Modeling and Simulation of a Manufacturing System Using ARENA®

By

Nurul Faezah Binti Mohhid (4459)

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
in partial fulfillment of the requirements for the
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(ELECTRICAL & ELECTRONICS ENGINEERING)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Dr Nordin bin Saad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NURUL FAEZAH BINTI MOHHID

ABSTRACT

The aim of this project is to develop a manufacturing system based on a practical situation implemented on the ARENA software. Notably, the project topic is applicable to most manufacturing companies, as it involves typical flows and conditions. It manipulates the movement of entities from one station to another, route to several processes with any specific condition, and finally being disposed. The main purpose of this project is to improve the process with weaknesses and lack efficiency by continuous process improvement and process reengineering. This project focused on the line balancing method which is usually done manually with high level of error, and also to observe the impact of machine procurement before being installed in an actual system. Data and observation of the real process was done on a selected production line of a manufacturing company producing color television. For each production line's main line, it has four main process areas: the assembly, adjustment, inspection and packing and each process has several more work positions under it. Four models are generated for output observation based on improvements applied. Model 1 represent the actual system, Model 2 represent the system with line balancing method, Model 3 represent the system with new machine procurement and model 4 represent the combination of Model 2 and 3. The models depend on inputs from historical data and fitted to specific distribution function via Input Analyzer tool. However another option for changes in input parameters is available through the VBA generated user form. The outputs can be viewed at the Microsoft® Excel, animation on ARENA itself and also Process Analyzer tool. The result shows the overall efficiency is improved by 22.26 %, throughput is increased up to 16.6 %, machine downtime is decreased by 59.9 % and WIP is decreased by 50.49 %. It can be concluded that a viable simulation model of the process is realized and the results obtained provide useful insights about the actual system and suggests ways of improving it.

ACKNOWLEDGEMENT

In the name of ALLAH, the Most Graceful and Most Merciful,

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ABBREVIATIONS & NOMENCLATURES

TV	Television
WIP	Work in progress
CRT	Cathode Ray Tube
DGC	De Gauss coil
DY	Deflection yoke
NS	Type of coil
G2	Screen voltage
HV	High voltage
AGC	Auto gain control
VBA	Visual® Basic for Application
ADO	ActiveX Data Object
IEEE	Institute of Electrical & Electronics Engineers

Takt	Completed product time rate
Kaizen	Improvement
Raku	Easy/flexible
Jig	Equipment purposely made for specific process

CHAPTER 1

INTRODUCTION

1.1 Background of Study

ARENA® software provides method to analyze current performance of the manufacturing process and any possible changes that could be made. By accurately simulating a process, a company can see the outcomes of changes without implementing them in real-time and save valuable time and excess resources [18].

A manufacturing company is chosen to be the data provider for this project. The study is done specifically on the smallest model of the television at the factory. There are about 15 production lines in the company. Daily, about 12 lines are opened for production and each line has their own working hour time pattern. The reliability of the manufacturing lines is depending on the efficiency and accuracy of workers, conveyor belts, machines used and all the process involved. It utilizes the operation of a continuous production in discrete manufacturing system (Figure 1.1). The product is moved from one operation to the next in manufacturing sequence.

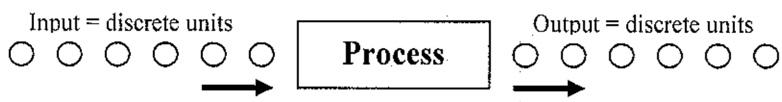


Figure 1.1: Discrete manufacturing [source: Groover, Mike P., Automation, Production Systems and Computer Integrated Manufacturing, Second Edition, Prentice Hall Int., 2001]

However the operation of the production line is complicated by the interdependence of the workstations on the line. Problems might occur from time to time such as unpredictability of equipment performance, bottleneck and unforeseen demand variation

[2]. Thus the correct course of actions needs to be implementing based on the simulations.

The production line selected is already operated for almost 5 years, and is allocated for small model type television since it was introduced. The online model is changed almost every year, but basically the standard operation procedure is almost the same. Improvements seeking for the line, which is also known as 'kaizen' is done every week to determine any improvements that can be done on the line. Thus this project can be said as one of the 'kaizen' done, but in simulation way rather than manually done.

1.2 Problem Statement

1.2.1 Problem Identification

Currently in Malaysia, production improvements are usually done manually. Basically seldom is the specific simulation technique applied for that matter. Workers will have to work overtime in order to reach the targeted demand rate in case the production does not reach the desired amount. It also involves manual calculation, rate charting and trial run over and over again in real time to determine any faults and countermeasures. This involves complex procedures and consumes a lot of time. An optimal way in overcoming this is to create and simulate the manufacturing operation using suitable simulation software, namely for this project, ARENA® simulation software.

1.2.2 Significant of the Project

Throughout this project, the application of the real time manufacturing process to the simulated one is carried out. The most significant value is the manual method of any changes/improvement in processes can be replaced by the software which provides easiness and helps increasing productivity in a simpler way in less time. The ARENA® simulation software product is the most ideal tool for predictive analysis applications that provides more alternatives, lowers the risks and increases the probability of success, without cost experimenting with the real system [18].

The problem focused on a specific production line of small type television model. The line requires 28 operators to conduct the line, as well as 1 technician and 3 leaders for monitoring and leading purpose. The first problem is that sometimes there occurred high WIP in certain process. This caused bottleneck, where the entities are blocked at certain section after completing their previous process. The reason is that the work station ahead takes too much time in completing their process. This problem can be improved by applying line balancing method in simulation style. The second problem is regarding to the machine breakdown. Here, simulation can be done to see the improvements after replacing the old machine that is suspected to have due their span time.

1.3 Objectives and Scope of Study

1.3.1 Objective

The purpose of the project is to develop a simulated process system based on a practical situation implemented on ARENA® software. The simulation objectives are:

- To simulate the model of manufacturing process and come out with the best way to improve workstation that has weaknesses and lack efficiency.
- To observe the effect of line balancing method and machine procurement to the level of efficiency and other parameters.
- To obtain and discern the number of output that can be produced within the most optimal time frame and modified resources.

This project have the impact on the author's skills in the process of applying data, expanding thoughts, solving problems independently and presenting findings through the software.

1.3.2 Scope of Study

The simulation is done on the main line part of the production line only. The preliminary study is mostly on the functions in ARENA® itself, automation and mechanical study and the operation chronology of the main line. The most important thing is the data gathering, to ensure process simulated have enough data to produce targeted result. Furthermore, the project is narrowed down to specific problem occurred at the manufacturing factory to obtain specific result. Additional application needed is the Visual Basic software which is then will be used to provide user interface function important for the online editing. The scope of this project will take into account the improvement of area that has weaknesses and lack efficiency. Readjustment of parameters in manufacturing such as the machine downtime and time cycle of the entities can be done to achieve improvements.

1.3.3 The Relevancy of the Project

Although the software is still not widely used in Malaysia, the best effort is to implement as much projects and researches on the matter so as to let manufacturers discover the benefits. This can contribute to the wider range of improvements in shorter time at the manufacturing system to the company and also nationwide. In short, this project is relevant to be one of the stepping stone in Malaysia industries.

1.3.4 Feasibility of the Project within the Scope and Time Frame

The project should be completed within two semesters, first semester being a data gathering session and the second being simulation session. However, there are some challenges faced, and this project does consume a lot of time as there are not much people in Malaysia who are skillful with the software. There are also a lot more things that can be applied in the simulation. Being the pioneer user of this software, the author is exposed to a lot of features and a lot of new ideas to be implemented. Since time is the limiting factor, the ideas can be applied in future student's project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

One of the most significant outcomes of the recent awareness to process improvement has been a rediscovery of the value of modeling [4]. As a consequence, it gives major impacts on manufacturing companies involved in terms of efficiency and eliminations of manual method/documentation. For example, a paper from Winter Simulation Conference discussed about a medium size manufacturer of chest freezers, which designed a simulation model on ARENA®. The simulation of actual operations was developed to ascertain its limitation and problem. It required an in-depth analysis of its manufacturing operations "in an attempt to increase its throughput and overall productivity rather than implementing the old manual method" [1]. At the same conference, a paper was discussed regarding the cycle time reduction for Naval Aviation Depots. The models constructed on ARENA® illustrate the effects of material availability and process redesign on repair cycle time and WIP inventory levels for critical components [2].

Another paper presents an overview of a simulation environment used for rapid modeling of memory chip line. The Electronics Manufacturing Simulator (EMS) is being used where the result reveals the bottleneck station and enhancement of the performance measures. The analysis includes rapid prototyping of electronics assembly lines, increased modeler productivity, reduced modeler knowledge, increased model flexibility, and improved model documentation [3]. All these strategies usually help users optimize specific performance and avoid costly mistakes by manual methods.

2.2 Description of production plant case study

In order to gain sufficient data as inputs to the simulation, several meetings with the engineers has been held, observing the real process to take process time and also for the author to be familiar with all the equipments there.

The actual production line consists of many block processes such as auto mount part process, hand mount process, dipped process, circuit test, board adjustment process and the main line [21]. However, only the main line is chosen to be simulated as it is the most crucial area for the production. The processes operate on the straight accumulating conveyor. It is said so as the entities will stop at each workstation and are released after a certain process time. Figure 2.1 shows the block diagram of the production line. Each block consists of several other sub-processes that total up to 28 value added activities. The layout of the production line, along with the resources can be view at Appendix 1

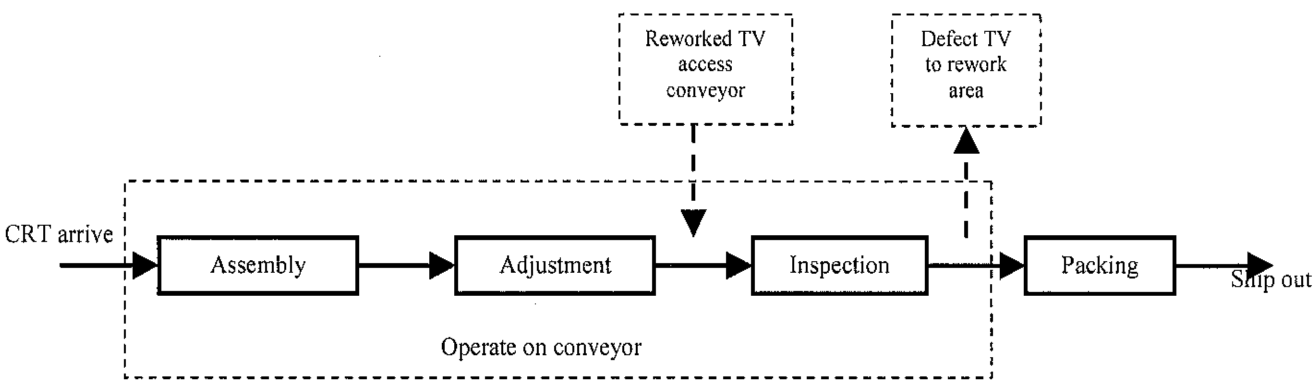


Figure 2.1: Workstations on the factory main line.

The conveyor has stopper in each work position. A pallet carries each entity throughout the line. The reworked TV need to access back the conveyor to go through adjustment and inspection again. Table 2.1 shows the common data of the production line.

Table 2.1: Common data of small model type of television [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme*]

OPERATION DATA	UNIT
Shift hour	12
Theoretical rate of product	88 television/hour
Average cycle time	836.14 s
Velocity of conveyor	1m/sec
Length of cells	6 feet
Machine failures	30 minutes (frequency : 10)
Total operators	28
Defect/reject TV (per day)	4
Rework process (average)	60 minutes
Shifts (per day)	2

2.3 Mainline data

Mainline for all television production lines can be separated by five blocks that are assembly, chassis, adjustment, inspection and packing. The first section of mainline is assembly process. It assembles the body or frame of the TV and process of board assembly. Figure 2.2 shows the process flow for these two processes.

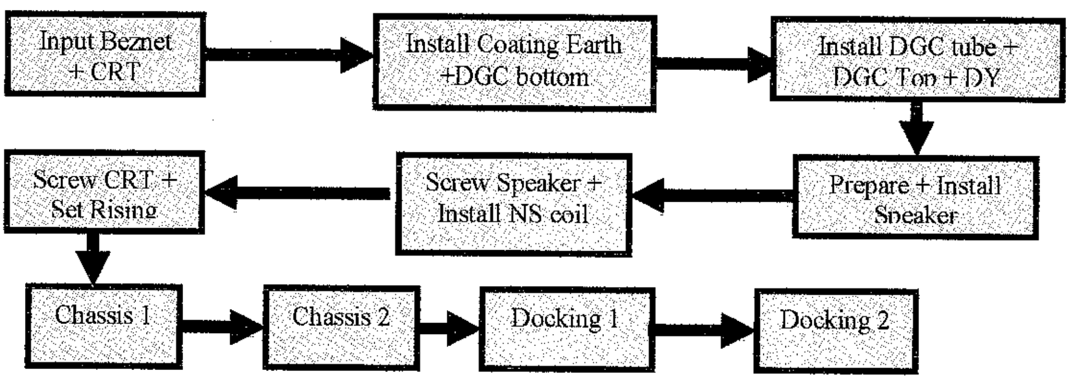


Figure 2.2: Assembly process blocks [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme*]

After the docking 2 process, rejected TV set will be removed for rework. Figure 2.3 and 2.4 shows the flow for inspection and adjustment process.

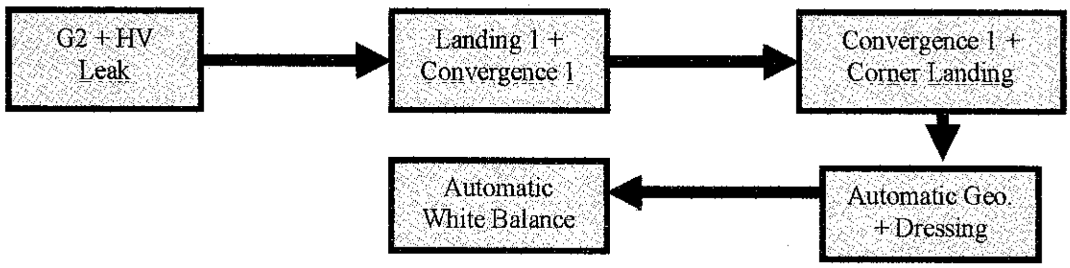


Figure 2.3: Adjustment process blocks [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme*].

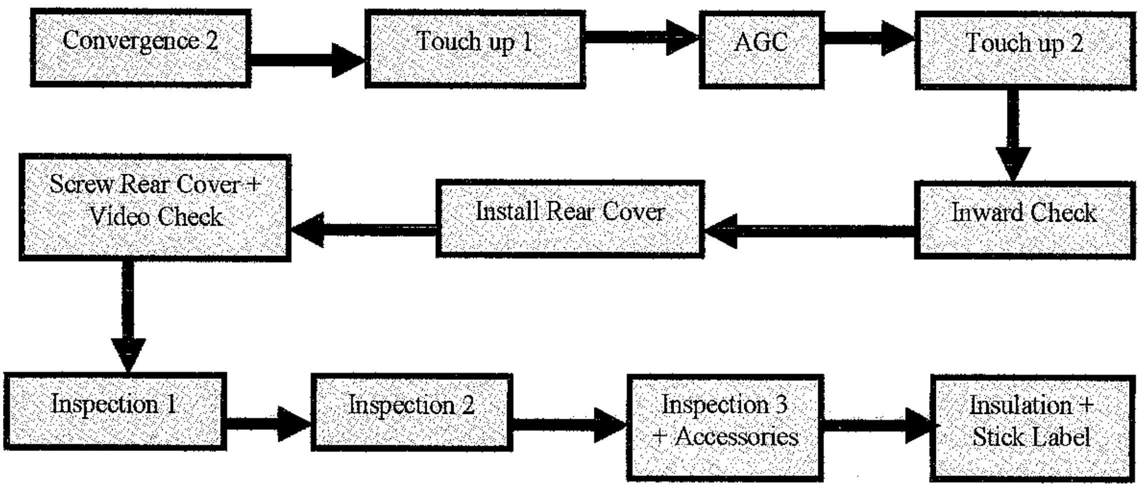


Figure 2.4: Inspection process blocks [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme*].

After the insulation and stick label process, rejected TV set will be removed for rework. The final part is the packing process where the TV set is moved from the conveyor belt, packed and sent to logistic department. The packing process is just the installment of completed TV set into their respective carton, along with the accessories. Figure 2.5 shows the flow of packing process:

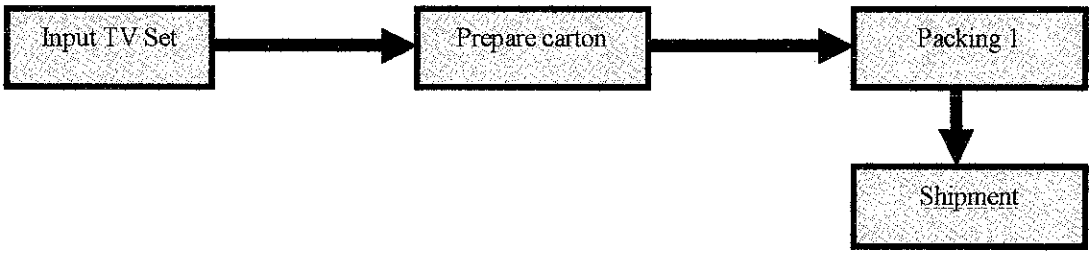


Figure 2.5: Packing process block [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme.*].

Table in Appendix 2 has been used as a guidance of accurate input. The processes that are necessary to build the model for the tests require 32 distinct processes. In building the model, data is taken for a number of times. This is to give a confidence interval in the processes as it is then distributed evenly in achieving a more accurate result [12]. Taken under consideration also is the allocation of the process, whether it is value added, non value added or transfer activities. For this simulation, the value added activities are considered as the most essential parameters for the line balancing method.

Rework process is considered as non value added as this process is a waste to the whole production line. However it is not taken into consideration for the process enhancement as the project is more focused main processes. Rework process is important to be included in the simulation model as it is an interdependent process with other processes.

2.4 Overview of problems

Production line must be designed to achieve a production rate sufficient to satisfy the demand for the product [7]. The production rate is usually expressed as an hourly rate; i.e. how many products can be produced in an hour. However the rate is seldom achieved for a newly introduced model on line.

The operation cycle time is the time that one work unit spends being processed or assembled including handling time. It also includes the run time, transfer time, waiting time until it reach the output area. The cycle time must take into account the reality that some production time will be lost due to occasional equipment failures, power outrages, lack of certain component needed in assembly, quality problems, labor problems and other reasons. As consequences of these losses, the line will be up and operating only a certain proportion of time out of the total shift time available; this uptime proportion is referred to as line efficiency [11].

At the factory, the process engineering department is responsible to maintain or upgrade the quality (zero defect), to increase productivity, plan to achieve the company target, and control the process flow effectively (consider the aspects of energy, time, space and cost saving). There are few suggested problem with their own solving method achieved from several resources at the company. The methods used are basically manual style, by observation, preparation and application, without the usage of any model simulation software, for example, the Japanese method (kaizen) which involves competition of groups of engineers to seek for any improvement that can be apply to the operation. All these use much time, effort and energy.

2.4.1 Identifying waste

There are seven types of manufacturing waste which are the nonproductive work, idle time, floor layout, lot size, product defects, overproduction and off-line manufacturing [5]. However, this project will be focusing on eliminating two wastes that are the idle time and overproduction:

i. Idle time – Resource is not being used to add value to the product. It is easy to detect waste from idle time by doing a walk-through of the production area to look for waste such as idle equipment. The three primary waste for idle time waste to occur are:

   a. Idle humans – Actions of avoiding improvement needs, chatting with other production employees, wandering around without doing works are all forms of idle time waste.
   b. Idle equipment – Equipment is not operating at the maximum time possible. This downtime leads to decreased product throughput. Neglecting equipment maintenance is also a waste. Equipment availability will drop and create production problems.
   c. Idle parts – throughput bottlenecks restrict parts from flowing through the process, which obvious by WIP queue in front of the bottleneck station.

ii. Overproduction – Occurs when product is built that is not required by customer demand. It is visually evident by large amounts of WIP stored between the operations. Effort is expended to produce product that will only be stored on manufacturing floor. This work is unneeded and disrupts the product flow through the process. examples of overproduction are:

   a. Operating equipments and resources to build parts that are only stored.
   b. Inventory costs to buy parts and floor space to store WIP.
   c. Additional handling of materials.
   d. Confusion and lack of purpose of operations.

2.4.2 Line efficiency

The purpose of line balancing is to maintain productivity and determine actual time needed to complete each operation at mainline production from input to output as it is virtually impossible to divide the work content time evenly among all workstations. [11]. Some process may not equally distributed as one process block can complete the work in short period of time while some bottleneck or WIP still occur at some other process block. This tends to increase number of workers. The line balancing method can decrease the manpower needed. However every production line has different flow time and it will vary with the model type also. This method is crucial as the factory receive new model almost every month which have different process time and other characteristics.

It is important to design the manufacturing method to be consistent with the rate at which the customer is demanding the product ('takt' time) [8]. It acts as a reference for every process time, which is the rate or time that a completed product is finished. Essentially it provides a rhythm for the factory to work at thus stabilizing the production [9].

$$\text{Takt time} = \frac{(\text{Work hour x 3600 sec})}{\text{Output plan}}$$

The normal time for an operation represent the time that a qualified operator would need to perform the job if the person worked at a normal tempo but it is not expected that a person will work all day without some interruptions. The operators may take time out for personal needs, for rest or for reasons beyond their control. The Personal and Fatigue Allowance which is 10% allowance is needed for the operators to alter their working tempo [9]. Another significant thing is to determine the line balancing efficiency. It is impossible to take the perfect 100% efficiency but it is important to make efforts so as to bring closer to it. It is considered good to achieve line balancing efficiency of 85 % and above [9].

$$\text{Balancing efficiency} = \frac{\text{Total process time}}{\text{Max time x No. of operator}} \text{ x } 100\ \%$$

Line balancing is made by focusing on bottlenecks while concurrently evaluated all areas of a process. Once a line is roughly balanced, the team continues reduce the cycle time by seeking new bottlenecks to optimize. The options are to combine the processes that take the least time or distributing works from workstation with excess workload. During the line balancing operation, all factors affecting the throughput is considered such as product defect, equipment availability and capacity, setup times, resource utilization, lot size and WIP build up [7].

2.4.3 Resource utilization

Another important factor is the utilization, whether applied on operators or the equipments. This is to determine the ratio of the number of parts made by the machine/ resource relative to its capacity. It is important for all resources to be fully utilized to make sure the job is equally distributed and achieved optimum amount of the resources utilizations, and to determine whether the resource is no longer capable [13].

2.4.4 Equipment performance

Reliable equipment is important for high-volume manufacturing. Equipment failure can stop the line with no throughput. The three different ways a process can improve are corrective maintenance, incremental improvement and quantum leap changes [4]. In this project, the improvement will be mostly on incremental improvement that involves the equipment only. It analyzes existing process conditions and makes small process changes. Each incremental change is based on improving the least optimum condition of the current process.

Although the production line is fully automated by human operators, some of the processes involve the utilization of machines. However, it can be seen that from year to year, that there is a pattern that the machine downtime is increased. This is due to the conditions of the machine; either they have due the span time or damage by any reason. The failure usually happens mostly during the start of the shifts. Table 2.2 shows the average downtime that occurs at for the small model type of television which has similar machine utilization.

Table 2.2: Average downtime per shift

Model type	Average downtime (minute)				
	May 2004	December 2004	May 2005	December2005	May 2006
Small A	15.62	16.58	20.31	30.94	-
Small B	25.72	29.43	-	-	-
Small C	12.30	13.51	18.95	30.44	31.62
Small D	-	10.81	14.52	12.16	25.55

The average downtime is about 40 minutes per shifts. The biggest contributor to this failure is the computer used for adjustment process. Table 2.3 summarizes the data of the machines involve:

Table 2.3: Machine downtime data (as October 2006)

Machine	Span time (years)	Workstation	Average downtime (per shift)	Contribution towards downtime
Raku hand 1	10	Initial station	0	0
Hand jack	10	Screw CRT_Set rising	0	0
Computer 1	5	G2 + HV Leak	6.57	16.43 %
Jig 1	5	G2 + HV Leak	1.97	4.93 %
Computer 2	5	Landing 1	6.74	16.85 %
Computer 3	5	Conv. 1_Corner landing	6.28	15.70 %
Jig 2	5	Auto geometry	2.06	5.15 %
Computer 4	5	Convergence 2	7.69	19.23 %
Voltmeter	10	AGC	1.87	4.68 %
Jig 3	5	Touch-up 2	3.10	7.75 %
Jig 4	5	Inspection 1	2.20	5.50 %
Oscilloscope	10	Inspection 2	1.52	3.80 %
Raku hand 2	10	Input TV	0	0
TOTAL			**40 min**	**100 %**

2.4.5 Determine problem via animation

The animation is important to determine whether the model is working correctly and to make the model look like the real system before allowing decision makers to view it. The status of the resources can be seen in the animation during the run and the parts can be tracked by looking at the resources. The animation can be improved by assigning images to parts that will provide the ease in following the parts during a production run. The essential aspects to be focused on animation are:

- Statistics – WIP, production output, resource utilization.
- Entity movements and queue size.
- State of resources

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

Simulation of a model requires a sequence of methodology, as discussed below. The purpose is to understand the behavior of the system and to evaluate strategies for the operation of the system.

3.1.1 Problem Formulation

The initial stage of the project is to identify the suitable manufacturing company with suitable production line in it. Some of the companies refuse to undertake the project due to data security purpose whereas the other did not believe in simulation method. A large-scale manufacturing company is chosen to be the data provider with their brand being anonymous by the mentioned reason. In this project, the line chosen has only gone through one improvement activities, thus it makes simulation a perfectly suitable tool to tackle any other unfound problem. The focus is to identify the biggest scope and narrowed it down to specific problems occurs during the manufacturing process which is to seek the problem definition, conditions of every process and any limitations. For the early stage, the problems found at the line are as below:

i. The mainline output did not reach the demand rate.
ii. The downtime average for all machines is too high.
iii. After viewing the pitch time form, it is obvious that the jobs are not being distributed evenly.

Before determining any feasible improvements to be applied to these problems, the actual improvement methods which are normally used are referred first. This is important when it comes to the verification and validation procedure. The model must allow the engineering decision makers (e.g.: engineer) to do improvements by means of:

i. Product throughput (maximized)
ii. Entities WIP (minimized)
iii. Resource utilization (maximized)
iv. Machine downtime (minimized)
v. No. of operators (minimized)

3.1.2 Model building:

Before the simulated model is being constructed, the basic idea must be roughly sketched, whether on the flow of the process or the main chronology. From here, the main idea can be visualized and customized from time to time. The line is physically laid out in 4 major areas:

i. Assembly (consists of ten workstations)
ii. Adjustment (consists of four workstations)
iii. Inspection (consists of ten workstations)
iv. Packing (consists of four workstations)

Before the mapping process, the suitable template in ARENA® is determined first. In this project, the model utilizes the Basic Process, Advanced Process and Advanced Transfer templates. Some of the modules in the templates correspond to the element modules, so every characteristics of the production line must first be defined for the user to get matching modules. Figure 3.1 shows the example of Advanced Transfer template:

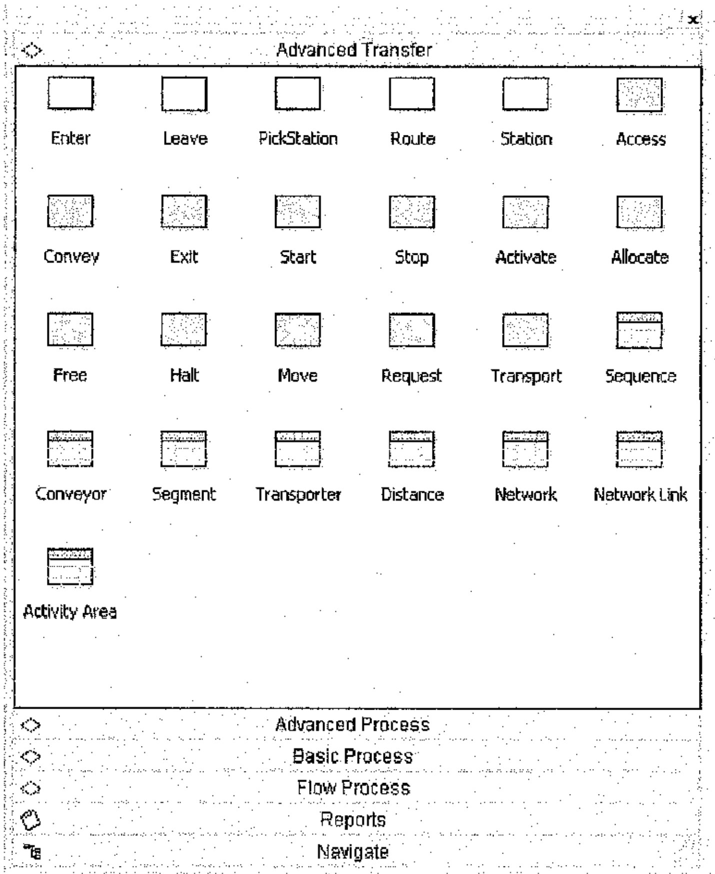


Figure 3.1: Advanced Transfer template

The model also contained user defined input parameter which is the process time and certain output must be accessible in Microsoft® Excel spreadsheet for.

3.1.3 Data collection

Data of each and every process for the mainline is captured through the engineering department of the company. Most of the data were extracted from the various production documents, but some, for instance the common data is given verbally from the engineers. These data are necessary in order to perform the analysis of existing production system. Due to confidentiality, the data is not presented in its original version. It is regenerated in order to conceal the confidential information.

3.1.4 Development of the simulation model:

Once the modeling assumptions are agreed during the model building stage, it can now be translate into the modeling software. Flowchart in Figure 3.2 shows the steps on using the ARENA® software:

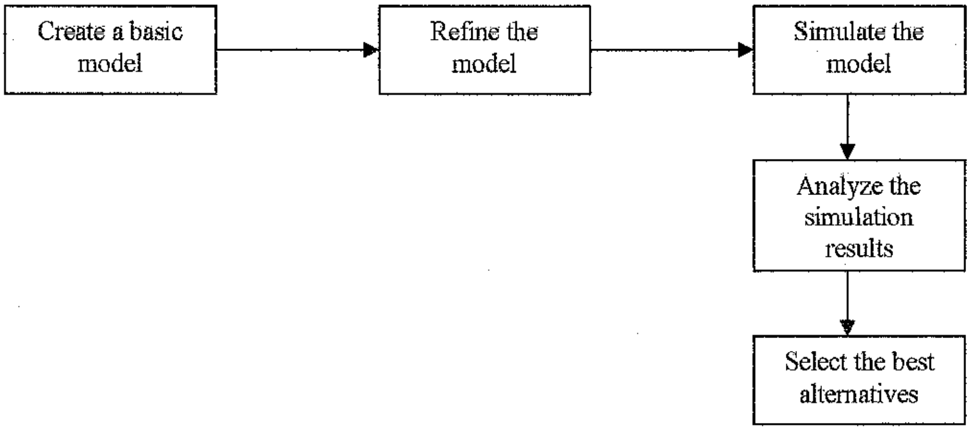


Figure 3.2: Steps of model translation

Model creation is done by dragging the modules into the model window and connects them to define the process flow. The most important thing is to add the real-world data and to refine the model, animation is done to make it more realistic. Some challenge occurs during the simulation, firstly to get the simulation to be similar with the actual system, and other problem that requires revision on the line itself during troubleshooting. The animation requires skills on designing that visualize the real operations on the production line.

The suitable code is generated to incorporate the VBA into ARENA® for online editing purpose. To export data from ARENA® to Microsoft® Excel, it requires File and Variable element, and also ReadWrite module in ARENA®. The function is to view the process time data and generate charts from it to determine whether the process times are balanced or not. Figure 3.3 shows the constructed model that is used throughout the project, whether in basic simulation or alternative design test. The nested model can be viewed at Appendix 3.

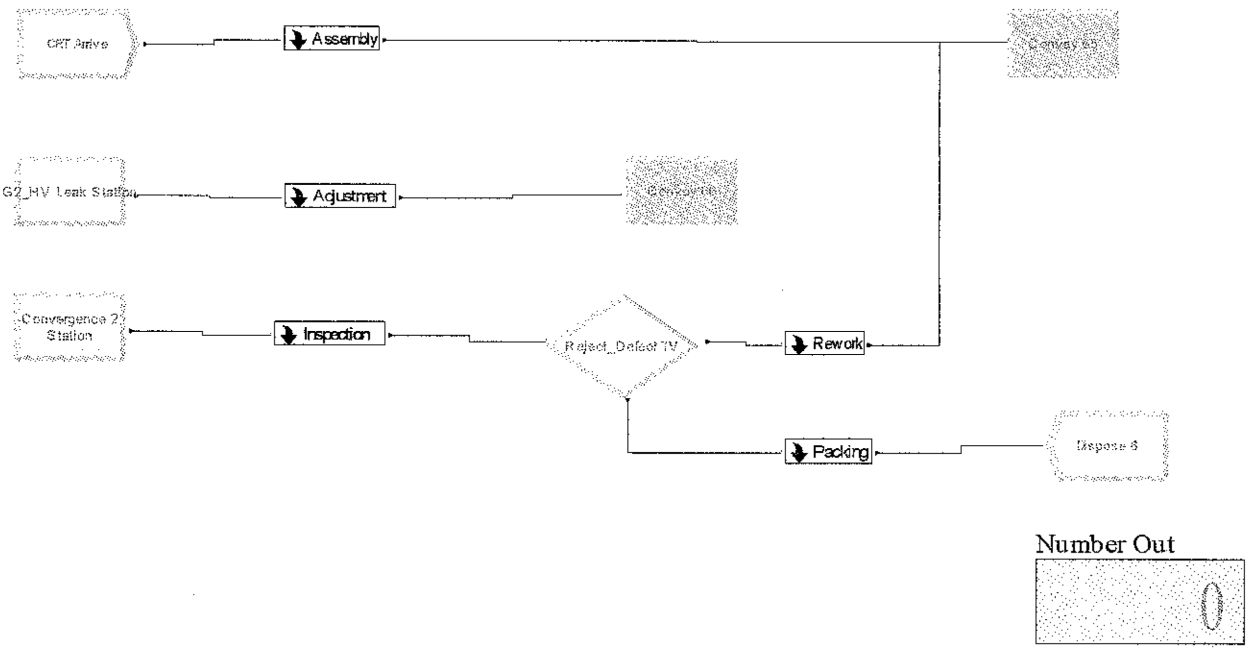


Figure 3.3: Model constructed

Figure 3.4 shows the animation of the model, which function is to provide clearer view to users in determining problems and statistics:

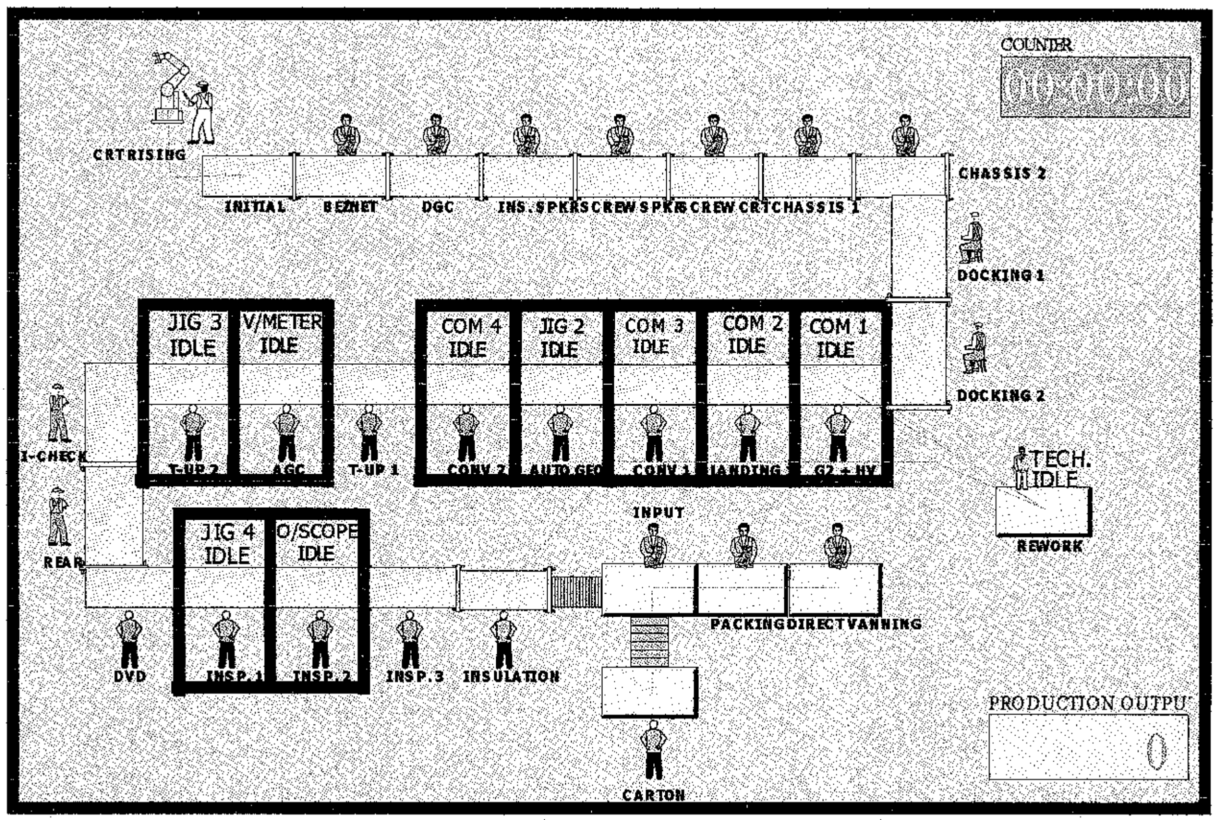


Figure 3.4: Animation

3.1.5 Verification and Validation

According to the IEEE Standard Glossary of Software Engineering Terminology, verification is defines as "The process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase." Validation, on the other hand, is defined as "The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements" [10]. So the simulation verification and validation defines the process of ensuring that simulation being developed or changed will satisfy functional and other requirements (validation) and each step in the process of building the software yields the right products (verification) [12].

The data and process is reviewed and tested thoroughly to make sure that system meets specifications by the input distribution match, and output performance measure whether they match with the actual system.

The simulation is run to verify that the model is similar to the real system. From here then users can determine any problems by visualize the animation, such as resource utilization and WIP. After the simulation ended, a sequence of summary report can be viewed, based on common decision. The final step is to make changes on model to get the most satisfied result.

3.1.6 Alternative Model Design

Four models are simulated, with each represents different parameters characteristics. In Model 1, it depicts the time cycle and activities happened in actual scene. Model 2 represents the model for line balancing method, which input parameters suitable with the changes done is used and the model also represents the online editing function for input process through VBA user form. Model 3 represents the system after new machine procurement. Finally, Model 4 shows the combination of the improvements done on Model 2 and 3.

Table 3.1 displays the difference in parameters for each model to view clearly comparison between the models that will be useful during report interpretation.

Table 3.1: Input comparison between models

Parent process	Sub-process involved	Model 1 (Actual)	Model 2	Model 3	Model 4
Assembly (Position = Conveyor)	Input Beznet → Screw CRT	Cycle time = 143.82 s	Cycle time = 138.1 s	Cycle time = 143.82 s	Cycle time = 138.1 s
Adjustment (Position = Conveyor)	G2 + HV Check → White Balance + Geometry	Downtime = 23.62 min	Downtime = 23.62 min	Downtime = 6.52 min	Downtime = 6.52 min
Inspection (Position = Conveyor)	Convergence 2, AGC, Touch-up 2, Inspection 1 & 2	Downtime = 16.38 min	Downtime = 16.38 min	Downtime = 9.52	Downtime = 9.52
Packing (Position = Not on conveyor)	Packing 1 → Direct Vanning	Cycle time = 32.77 s	Cycle time = 28.05 s	Cycle time = 32.77 s	Cycle time = 28.05 s

3.1.7 Model Runs and Output Analysis

This is the last stage of the simulation, where the simulation must be working out and carry the right kinds of statistical analysis to be able to make accurate and precise statements [17]. This is clearly tied up with the design of the simulation experiments. Analysis is implemented to determine any missing data. Trial and error method is also done on the simulation to figure out any error for any parts of process to be corrected. During this stage, the expectations must be planned out and determined to get the results in precise and efficient way.

3.1.8 Documentation and Report Result

Documentation is important for getting attraction from the management and implementation of the recommendations of the model constructed with precision and confidence. The detailed report is provided in ARENA® and can be viewed after each simulation.

3.1.9 Implementation

If the outcomes are sufficient enough to generate improvements to the manufacturing system during simulation, the implementation of the improvements can then be applied at the actual system. However this is due to the management decision.

3.2 Tool Required

3.2.1 ARENA® software

ARENA® software is chosen as it allows creation of model and running experiments on model of a process. The system can then predict the future with confidence and without disrupting the current flow environment [16].

3.2.1.1 Input Analyzer

The function is to fit specific distribution functions to a data file to allow user to compare distribution functions or to display the effects of changes in parameters for the same distribution. The data files processed by the Input Analyzer typically represent the time intervals associated with a random process, captured at the actual process [17]. The best fit is chosen to be the distribution to be used. Figure 3.5 shows the data fit windows which contain the histogram and information on the distribution.

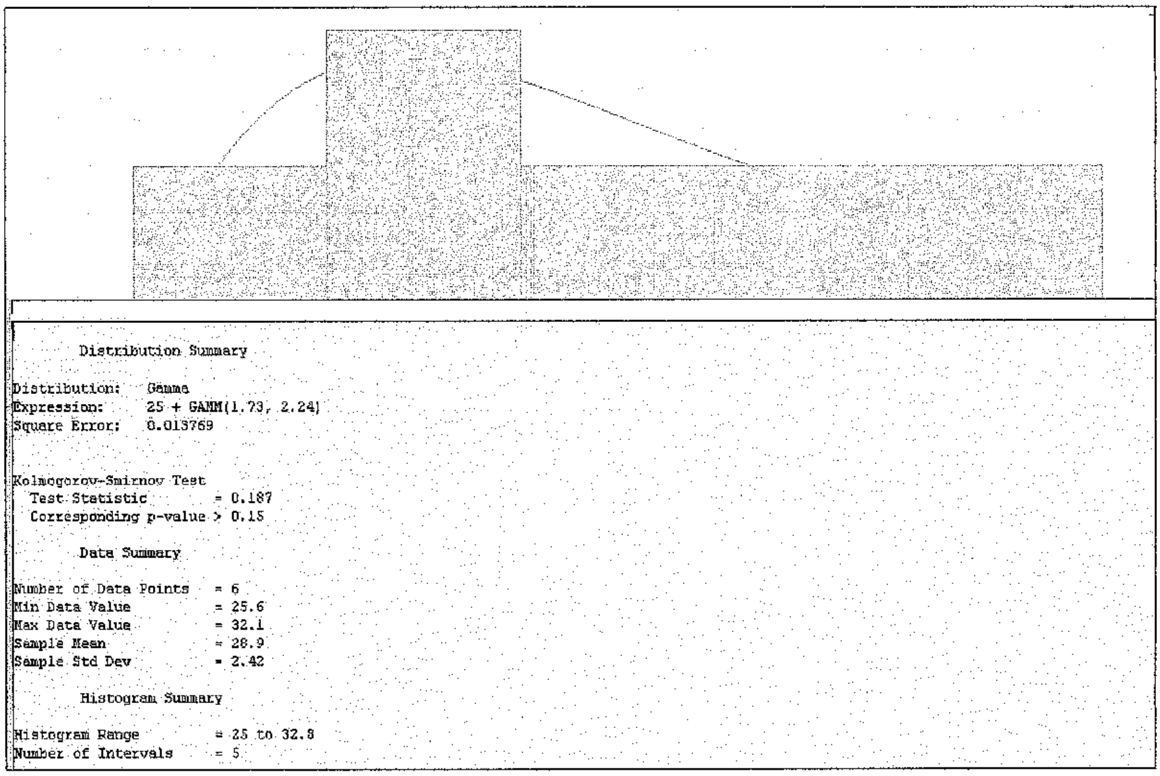


Figure 3.5: Data fit window

Most of the distribution used for this project is Beta, Triangular, Weibull, Uniform, Normal, Gamma and Lognormal. The expression of the distribution is being used later to express any inter arrival time or process time. Appendix 4 shows the list of distribution used to be input of the processes.

3.2.1.2 Time Pattern Editor

The Time Patterns Editor is used to define Capacity and Efficiency Time Patterns. As been chosen for this simulation, a 'Capacity Time Pattern' defines the whether or not a resource will be available over time. Most resources will either be available (1) or unavailable (0). The factory standard work shift is as below:

Table 3.2: Working hour by shifts

Shift 1		Shift 2	
Time duration	Status	Time duration	Status
6.15 – 8.15 am	Online	6.15 – 7.15 pm	Online
8.15 – 8.30 am	Break	7.15 – 7.30 pm	Break
8.30 – 11.30 am	Online	7.30 – 1.30 am	Online
11.30 – 12.00 noon	Break	1.30 – 2.00 am	Break
12.00 – 2.30 pm	Online	2.00 – 4.30 am	Online
2.30 – 2.45 pm	Break	4.30 – 4.45 am	Break
2.45 – 6.15 pm	Online	4.45 – 6.15 am	Online

For this 12 hour shift, the total of break time is 1 hour. The time pattern generated is shown below, which displays the total working hour for the day where the shifts' working hour is defined in the Shift 1 and Shift 2 file as shown in Figure 3.6.

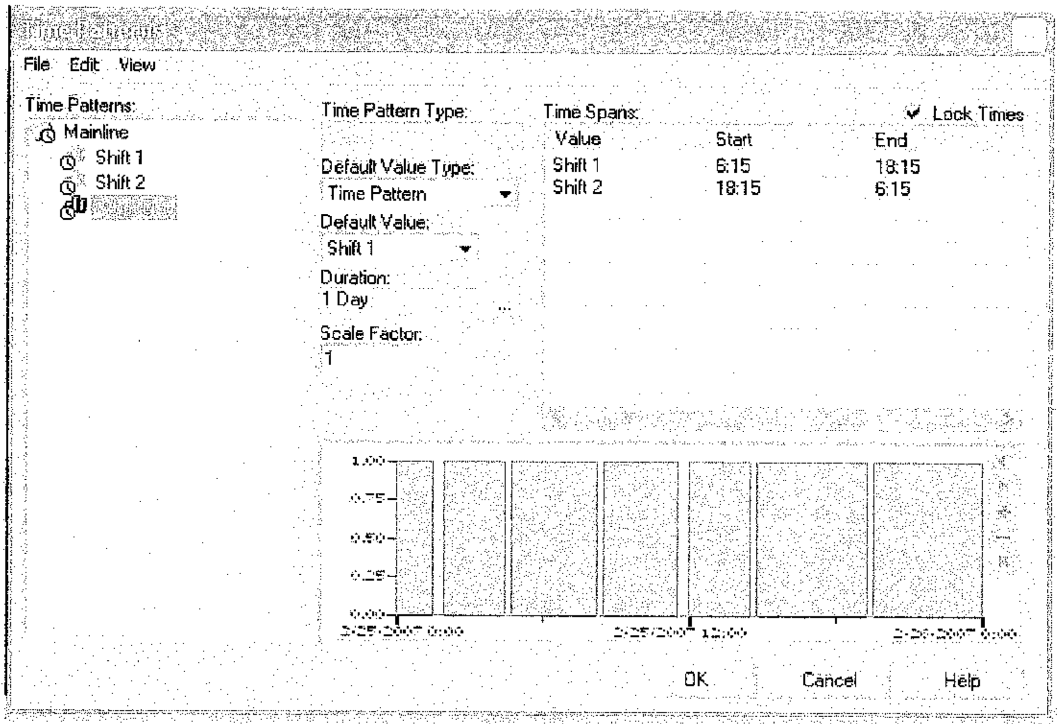


Figure 3.6: Workday time pattern

3.2.1.3 Process Analyzer

Process analyzer is another tool in ARENA® for performance plotting. It provides option of viewing and charting results and comparison of alternatives. The role is also to allow for comparison of the outputs from validated models based on different model inputs [18]. Possible inputs, called controls, are variable values and resource capacity. The outputs, called responses, can be variables, or any type of ARENA® statistic [17]. There is no needs to exporting and generate separate file thus produce instant result.

3.2.2 External software

3.2.2.1 VBA

The interface to VBA is a separate window, integrated with ARENA®, in which any editing, designing, and debugging code and forms are done [12]. The function for this project is for online editing where any instantaneous improvements for process time is inserted in the generated user form, thus producing faster result instead of defining the parameters using input analyzer. Basically this is also to present one of many approaches on validating a model, by running the simulation logic using the actual process time collected from the real system (historical data). Instead of using process time based on sampling from a probability distribution, the record on that very time is inserted in a user form generated using the VBA. It provides benefits, from process improvement (by line balancing) to alternating the utilization of production line between many model types. Another significant value is that this interface gives advantage on simulating process for different flow time and eliminated processes.

3.2.2.2 Microsoft® Excel

This tool is useful to view any user specified result, for the benefit of the users who are not familiar with ARENA® software and for result modifications. Charts of the result are generated here.

3.2.3 Dongle

The dongle is needed for the software activation. It is also called node-locked; this type of activation is saved on a computer's hard disk, but is locked to a particular hardware dongle [13]. When the dongle is present, the activation can be used on the computer. When the dongle is absent, the activation cannot be used on the computer.

3.2.4 A computer

The computer is used to do the simulation, programming and the processing of the experiment's data.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Model 1 which is the model that represents the actual system simulates 28 value-added processes; 26 processes are on conveyor while the remainder is on normal workstation. During the model construction, any minor issues need to be considered as one single error that appears during model checking can lead to model malfunctioning. The following parameters are specified in order to get precise result:

i. Length of each simulation run = 24 hours
ii. Length of the warm up period = 12 hours (to achieve steady state simulation)

The results of the simulation are divided into four which are verifying and validating, alternative model test, model development and result analysis.

4.2 Verifying and validating (Model 1)

The first phase of the simulation is focused on getting the production rate and cycle time similar with the actual system. This is the most essential matter, as from here the first validation is achieved and any model expansion can proceed.

Table 4.1: Comparison of actual system and simulation

Parameters	Actual system (second)	Simulation (second)	% difference
Cycle time	887.08	899.84	1.438 %
Production rate	0.0676	0.0667	1.363 %

From Table 4.1 it can be conclude that the percentage of difference between the actual system and the simulated model is relatively small and will produce small error. The animation of Model 1 in Figure 4.4 displays the production output:

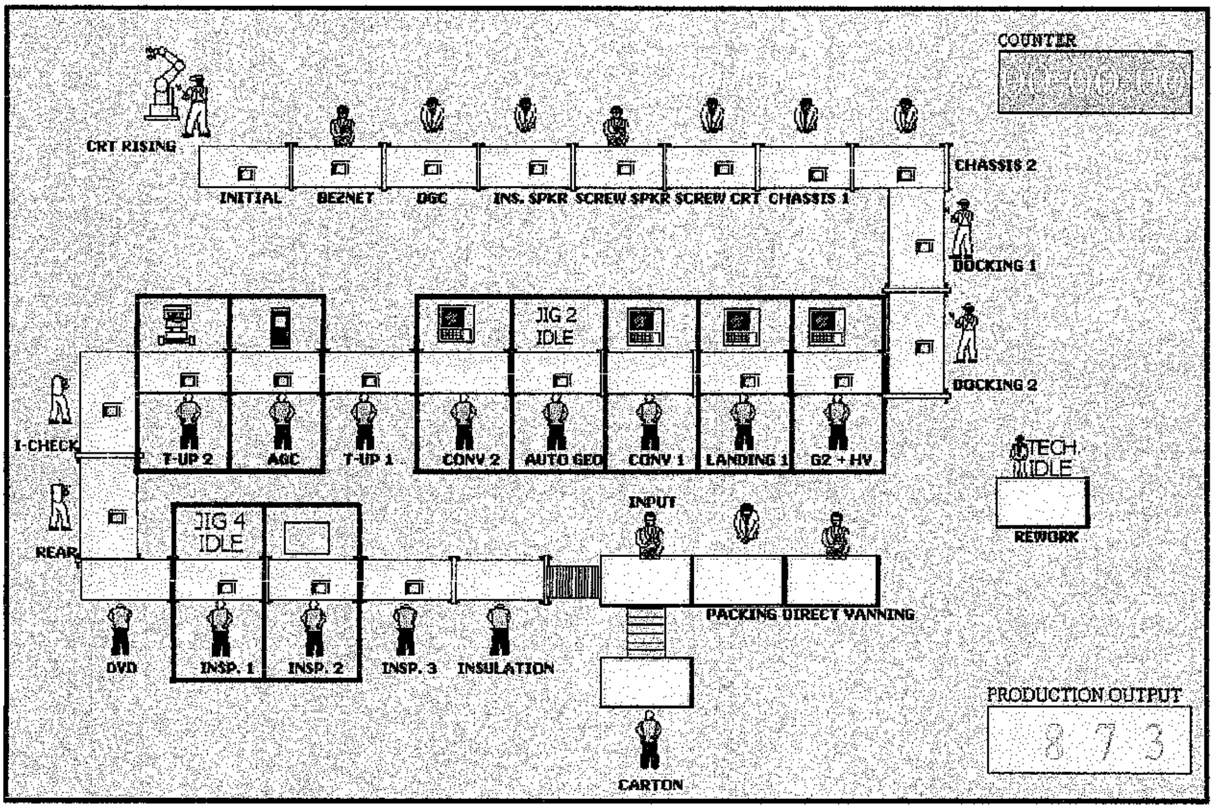


Figure 4.1: Model 1 animation, output produced for 12 hour shift.

4.3 Alternative model test

4.3.1 Line Balancing (Model 2)

The production demand is 880 units per shift. For this production line, the takt time plan is calculated as below:

$$\text{Takt time} = \frac{(\text{Work hour x 3600 sec})}{\text{Output plan}}$$

$$= \frac{11 \times 3600}{880} = 45 \text{ second}$$

With 10% allowance = 110% x 45 = 40.5 second

Actual system

For Model 1, the WIP and resource percentage of utilization monitoring screen is shown at Figure 4.5. From this data monitoring, the value of utilization per process done can be seen directly, where the utilization percentage for Install speaker, Screw speaker, Auto Geometry, Inspection, Packing and Direct vanning processes are quite low. While for WIP screen, it can be said that the WIP is quite high.

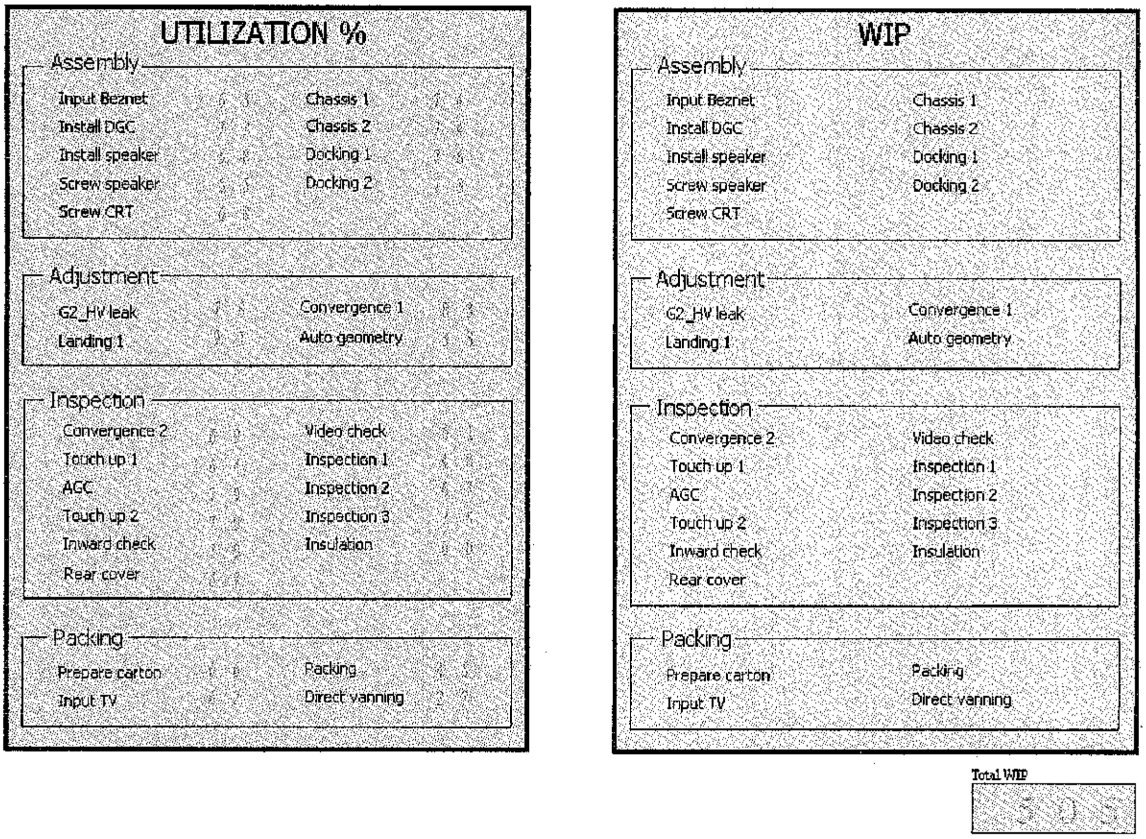


Figure 4.2: The variables animation

From the observation on the process time at the exported data at Microsoft Excel, the flow time is not balanced for each process. One of the process times exceeds the takt time with 10% allowance, while the others are not balanced. Figure 4.6 shows the chart for the process time.

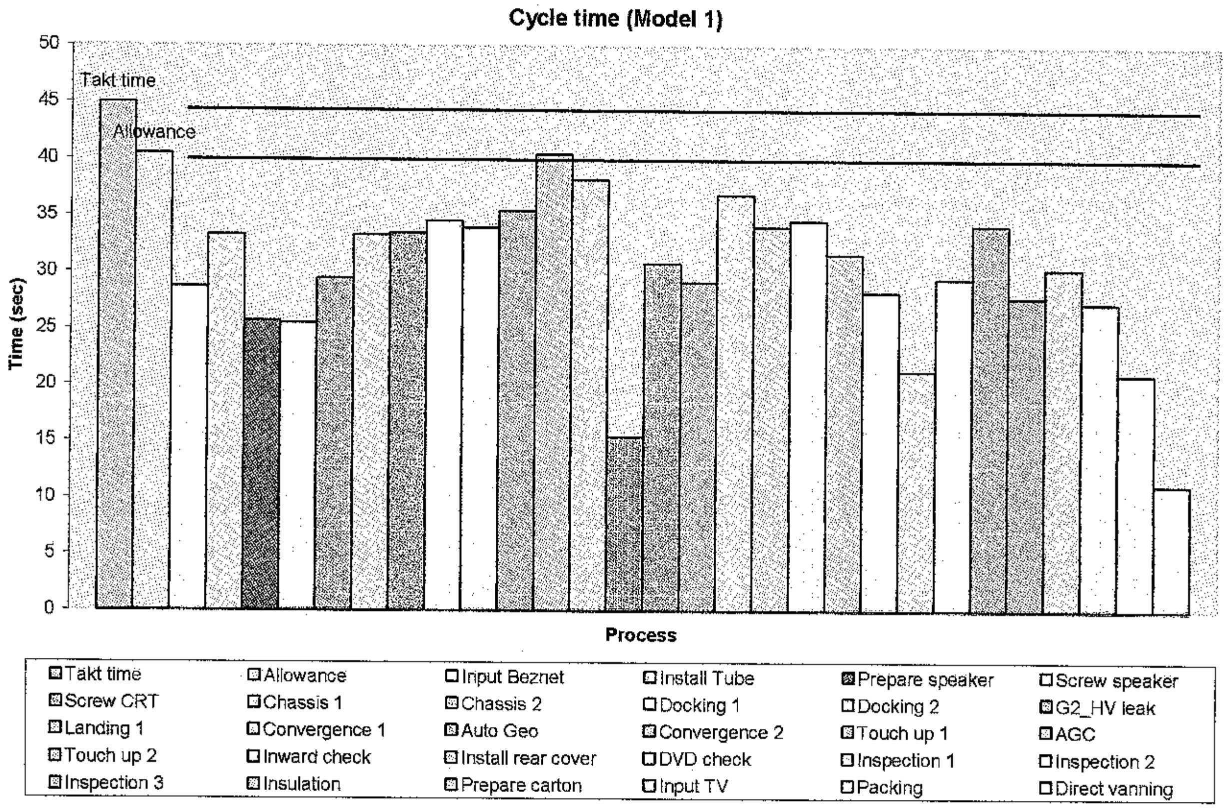


Figure 4.3: Process time chart

The demand rate is not achieved, so this line balancing method is one of the ways of determining any hindrance that could obstruct the line to achieve the demand rate.

Output = 873 unit (not achieved)

Calculation:

$$\text{Balancing efficiency} = \frac{\text{Total process time}}{\text{Max time x No. of operator}} \times 100\ \%$$

$$= \frac{836.14}{40.89 \times 28} \times 100\ \% = 73.03\ \%\ \text{(not good)}$$

Table 4.2 shows the flow time of every process at the main line, before and after improvements. This is applied at the newly introduced small television model type A.

Table 4.2: Line balancing method [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme.*]

NO	PROCESSES	AVERAGE (BEFORE) (Second)	AVERAGE (AFTER) (Second)
1	Input Beznet + CRT	28.73	33.98
2	Install tube + DGC + DY	33.19	35.31
3	Prepare speaker	26.52	34.36
4	Screw speaker	25.13	0
5	Set rising	30.25	35.45
6	Chassis 1	33.68	33.68
7	Chassis 2	33.69	33.69
8	Docking 1	34.6	34.6
9	Docking 2	33.2	33.2
10	G2 +HV check	35.05	29.14
11	Landing 1	40.89	34.16
12	Conv. 1_Corner landing	37.77	32.67
13	White balance + Geometry	15.02	32.76
14	Convergence 2	31.33	31.33
15	Touch-up 1	28.87	28.87
16	AGC	35.29	35.29
17	Touch-up 2	35.41	35.41
18	Inward check	35.61	35.61
19	Rear cover	30.54	30.54
20	Video check	27.7	27.7
21	Inspection 1	21.9	21.9
22	Inspection 2	30.15	30.15
23	Inspection 3	33.89	33.89
24	Insulation	26.98	26.98
25	Prepare carton	29.87	29.87
26	Input	28.11	28.11
27	Packing 1	20.57	0
28	Direct vanning	12.20	28.05
TOTAL		**836.14**	**826.7**

Note:

Blue font indicates the changes that have been made.

Improved system

By observation and comparison of the tact time with the process time, it can be seen that some improvements can be made:

i. Problem : Unbalance input area time

Countermeasure : a) Combine Process 3 and 4.

b) Counting CRT screw and dressing process from Process 3 and 4 are transferred to Process 1, 2 and 5 (Count + dressing time : 9.87 second)

Effect : Decrease manpower, decrease the resource cost, balanced process time, increase throughput.

ii. Problem : Low Process 13 time.

Countermeasure : Transfer the dressing Process 10 and 11 to Process 13.

Effect : Balanced process time, reduced WIP, increase throughput.

iii. Problem : Low Process 27 and 28 time.

Countermeasure : Combine Process 27 and 28.

Effect : Decrease manpower, decrease the resource cost, balanced process time, reduced WIP, increase throughput.

Calculation:

$$\text{Balancing efficiency} = \frac{\text{Total process time}}{\text{Max time x No. of operator}} \times 100\,\%$$

$$= \frac{826.7}{35.61 \times 26} \times 100\,\%$$

$$= 89.29\,\%\ (< 85\,\%)$$

The output for this model is increased to 996 and can be viewed via the animation in Appendix 5. The increased production output percentage:

$$\frac{\text{Improved} - \text{Actual}}{\text{Actual}} \times 100\ \%$$

$$= \frac{996 - 873}{873} \times 100\ \%$$

$$= 16.6\%$$

The simulation can also be useful to estimate the effectiveness of manufacturing process. Table 4.3 shows the inter arrival time per unit television at the final workstation.

Table 4.3: Manufacturing result for small model television

Unit produced	Before		After	
	Time taken (minute)	Inter arrival time p.u (second)	Time taken (minute)	Inter arrival time p.u (second)
0	0	0	0	0
100	88.837	53.30	82.463	49.48
250	214.591	51.48	198.699	47.68
500	428.268	51.42	396.382	47.56
750	626.005	50.08	577.933	46.23
1000	871.938	52.32	810.085	48.6

Average inter arrival time per unit (before):

$$= \frac{53.3 + 51.48 + 51.42 + 50.08 + 52.32}{5}$$

$$= 51.72 \text{ second}$$

Average inter arrival time per unit (after):

$$= \frac{49.48 + 47.68 + 47.56 + 46.23 + 48.6}{5}$$

$$= 47.91 \text{ second}$$

$$\% \text{ difference} = \frac{\text{Avg (before)} - \text{Avg (after)}}{\text{Avg. (before)}} \times 100\%$$

$$= \frac{47.91 - 51.72}{51.72} \times 100\%$$

$$= -7.367\,\% \approx 7.4\% \text{ decreased.}$$

4.3.2 Machine procurement (Model 3)

For this experiment, observation is done at another production line where machine replacement has taken place, to capture the process time. From observation at the line itself, it can be said that the problem are mostly caused by increased in setup time and software failure to respond. The computer contributes up to 75.13% of the downtime. This evidence led to a proposal of a set of feasible modifications to the production line in an attempt to decrease the machine downtime thus increasing its throughput and overall productivity. By viewing the maintenance reports also, it is obvious that the computers have been used exceeding their span time (five years six months by October 2006).

Table 4.4 shows the simulation result of cycle time per unit after the computers have been replaced. It is specified that the new computer have zero downtime, after doing some observation on new computer performance at another production line.

Table 4.4: Downtime comparison table

Computer	Workstation	Before			After		
		ST	FT	Total	ST	FT	Total
1	G2 + HV Leak	3.28	2.29	6.57	0.83	0	0.83
2	Landing 1	3.13	2.61	6.74	0.83	0	0.83
3	Conv 1_Corner landing	2.49	2.79	6.28	0.83	0	0.83
4	Convergence 2	3.97	2.72	7.69	0.83	0	0.83
TOTAL		**12.87**	**10.41**	**27.28**	**3.32**	**0**	**3.32**

Keyword:
ST – Setup time
FT – Failure time

After the simulation, by replacing four computers the output for this model is increased to 897 and can be viewed via the animation in Appendix 6. The downtime is lesser and more constant. Table 4.5 shows the simulation result of cycle time per unit after the computers have been replaced.

Table 4.5: Cycle time comparison table

Machine	Workstation	Cycle time		Remarks
		Before	After	
Computer 1	G2 + HV Leak	35.05	39.12	Increase
Computer 2	Landing 1	40.89	44.91	Increase
Computer 3	Conv 1_Corner landing	37.77	41.62	Increase
Computer 5	Convergence 2	31.33	35.15	Increase

The ARENA® report shows that the cycle time increase after the machine replacement. This is due to the reduced downtime, thus the production runs more smoothly and as a consequence, the cycle time increase. The waiting times for some of the workstations involved increase, while other workstations which do not involved, also increase because the workstations are all interdependent. This situation can generate bottleneck. There are two options to counter this problem which and these are:

i. Apply line balancing first before simulate the operation with machine procurement.
ii. Apply line balancing method after the machine procurement.

The comparison of Model 1 and Model 3 cycle time can be viewed at Appendix 12.

4.4 Model development

4.4.1 User forms by VBA

User form that contains textboxes for data insertion appears before the simulation run (see Figure 4.1). This form is applied at Model 2 and Model 4. User insert actual data instead of using data based on sampling from a probability distribution provided by Input Analyzer. The main purpose is to take the value stored in the textbox, "Textbox" (1 to 28) and through automation, places it into the module operand named "Value" [19].

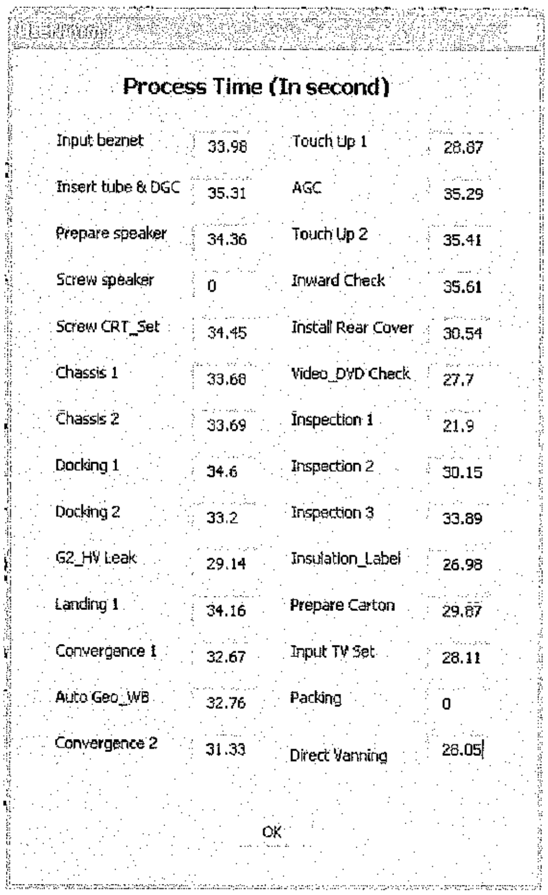


Figure 4.4: Input data user form

As additional to the input value user form, another two user forms will be displayed to all models when the model run begins and ends. The first one provides a description of its purpose, and then allows the user to click to begin the run (see Figure 4.2). At any time during the run the user may pause the model, which will cause the second user form to appear. This form provides some more information that allows the user to choose to continue or to abort (see Figure 4.3). The VBA codes for these user forms can be viewed in Appendix 7.

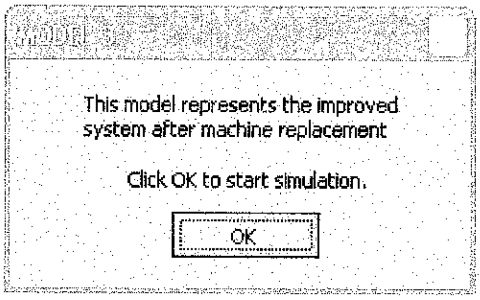


Figure 4.5: Welcome form

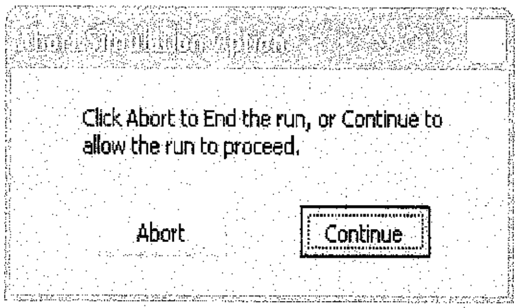


Figure 4.6: Action form

4.4.2 Export data to Microsoft® Excel

The data transfer activity is applied to all models. The spreadsheet must be opened during the simulation run to ensure data is directly exported into the destined file. The preceding line balancing method is done based on the Model 1 chart, where users can visually see the unbalanced process time, and then see the impact after applying some modifications on it. Appendix 8 shows the exported data as well as generated charts for each model. The charts are divided into 2 that are the process time chart (calculated mode), and also the process time plus downtime chart (downtime occurs at actual operation). It can be observed that after line balancing, the jobs are evenly distributed and under takt time with allowance (Model 2). While for model 3, some of the process time exceeds the takt time with allowance. So this model needs line balancing method, which is applied at Model 4.

4.4.3 Monitoring via animation

Users may need to monitor the instantaneous performance of the production line. Thus the animation screen for the WIP and the percentage of utilization are generated. These 2 screens basically display the variables of the two parameters for users to visually identify any bottlenecks and to determine the resource capacity instantaneously, as shown in Appendix 9. The results for the 4 models are then plotted at the process analyzer for comparison. Improvements are done based on these data, as for example, improvement for resources with very low utilization percentage to make it balance with other resources, which is done during the line balancing.

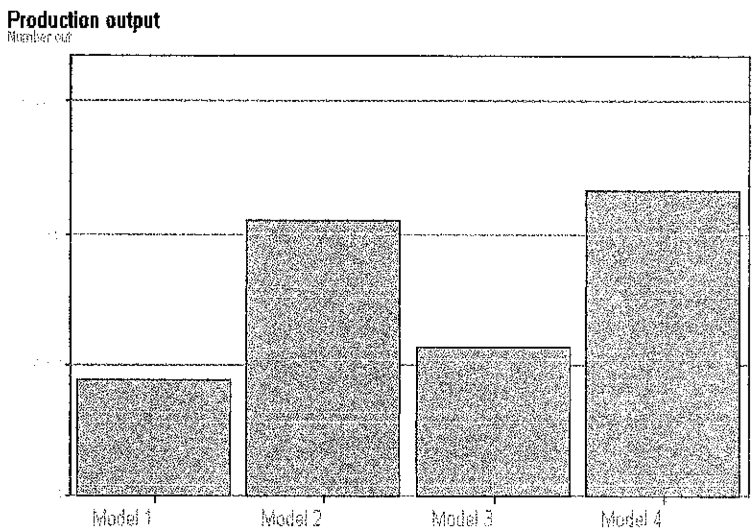
4.5 Result analysis: Process Analyzer

The comparison of any scenarios or parameters is done here, apart from directly looking at the ARENA® report itself. Possible inputs, called controls, are chosen to be all resources capacity. The outputs, called responses, are chosen from the statistic.

4.5.1 Resource utilization

The results for resource utilization can be viewed at Appendix 10. After applying the improvements, the result shows that the resource utilization increases for Model 2, 3 and 4 due to the balanced job distribution and increase in machine effectiveness.

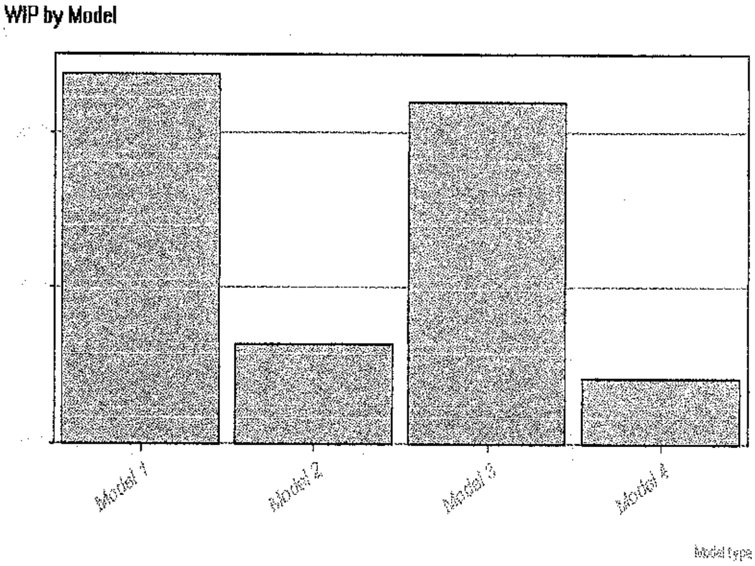
4.5.2 Production output



Model	System.NumberOut
Model 1	[illegible]
Model 2	[illegible]
Model 3	[illegible]
Model 4	[illegible]

Figure 4.7: Comparison chart for production output

4.5.3 Work in progress



Model type	CRT.WIP
Model 1	[illegible]
Model 2	[illegible]
Model 3	[illegible]
Model 4	[illegible]

Figure 4.8: Comparison chart for WIP

4.6 Discussions

The outcome of the simulation study with current manufacturing system (Model 1) shows that:

a) The predicted number of units produced is similar to the number actually produced (on average with same time applied).
b) The number of units produced is slightly lower than the demand rate.
c) Machine downtime always occurs to four computers at the adjustment process.
d) Jobs are not distributed evenly at some of the processes thus generating high WIP accumulation.

4.6.1 Line balancing

The line balancing activity involves simulating the processes before and after modification, with aim of accurate result. Some challenges occur, such as during the simulation of Model 2 (after modification). The output result is not as expected. The author finds out that the processes are dependant with each other. Changes done on a process may give big impact to other process. To generate a better output, each and every process must have quite similar process time, that is also must be below than the takt time with 10% allowance.

All these decision regarding to this activity needs to be discussed thoroughly with the person related and referred to elemental jobs first to check all the sub processes done. For example, for the first problem, it is based on the engineer experience to distribute the sub processes evenly so that the process time can reach the tact time. The engineer must have the common knowledge of every elemental job in the factory as most of elemental jobs are actually used in every production line. The methods done on this line balancing process are usually by trial and error. The engineers will determine which sub processes are to be transferred to other process blocks and then implement it on actual system to see the attempt is successful or not. While on ARENA®, these data is obtained from observations and discussion with the engineer at the factory. Simulation is done at the model with VBA interface to write input data.

4.6.2 Combination of improvements

Model 4 simulates the combination of line balancing and machine procurement, to see the consequences and changed in parameters value. The results can be viewed at the Appendix 11 and also at the process analyzer parts, where it can be concluded that the combination of both activities gives more increase to the production output. While the increase is exceeding the demand rate, the shift time can be reduced to avoid overproduction:

Demand rate	=	880
Production output	=	1018

After simulating Model 4 with production output specified to 880, the resulting simulation time is 10.93 hour. So with the improvements on this model, the shift time can be reduced to 11 hours only. From the result also, can be seen that the production output is increased compared to the actual system:

$$\% \text{ increase} = \frac{92.54 - 79.36}{79.36} \times 100\,\%$$

$$= 16.6\,\%$$

4.6.3 Cost Analysis

The cost analysis is done based on Malaysian Accounting Standard Boards [15] as below:

Basic payment (level O operator))	=	RM 475.00
Working hour (Normal day)	=	8 hours
Shift duration	=	12 hour
Overtime	=	4 hour

Operator cost per hour (Normal working hour)

$$= \frac{\text{Basic}}{26 \times 8} = \frac{\text{RM } 475}{208} = \text{RM } 2.28$$

Operator cost per day (Normal working hour)

$$= \text{RM } 2.28 \times 8 = \text{RM } 18.24$$

Operator cost (overtime < 8 hours)

$$= \frac{\text{Basic}}{26 \times 8} \times 1.5 \times \text{Overtime hour}$$

$$= \frac{\text{RM } 475}{208} \times 1.5 \times 4 = \text{RM } 13.70$$

Operator cost per shift = RM 18.24 + RM 13.7

= RM 31.94

Model 1

Total operators cost per shift = RM 31.94 x 28 operator

= RM 894.32

Model 2 & 4

From the line balancing method, about 2 resources can be eliminated. With 2 operators elimination,

Total operators cost per shift = RM31.94 x 26

= RM 830.44

By reducing two manpowers, about RM 63.88 can be reduced per shift. This contributed to cost reduction up to RM 30 662.40 per year, if the same model is online throughout the year.

4.6.4 Different model type

As the manufacturing company produces many model types and sizes of television, these televisions also have different characteristics such as different process time, amount of resources, demand rate, production rate and also different shifts. The simulation can be applied pertaining to these characteristics, as the processes are almost similar and different process time can be inserted into the user form generated by VBA.

4.6.5 Result comparison

Table 4.6 shows the comparison between the performance measures for all models.

Table 4.6: Performance comparison between models

Performance measures	Model 1 (Actual system)	Model 2 (Line balancing)	Model 3 (Machine procurement)	Model 4 (Combination 2 & 4)	% difference (Model 1 & 4)
Total work in progress	505	276	481	250	50.49%
Resource cost (per shift)	RM 894.32	RM 830.44	RM 894.32	RM 830.44	7.14 %
Resource capacity	28	26	28	26	7.14 %
Line efficiency	73.03 %	89.29 %	73.03 %	89.29 %	22.26 %
Production output	873	996	897	1018	16.6 %
Production rate	79.36	90.54	81.54	92.54	16.6 %
Machine downtime	40 min	40 min	16.04 min	16.04 min	59.9 %
Shift time	12 hour	12 hour	12 hour	11 hour	8.33 %

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

The result from the simulation work provides very useful information on what could be done to improve the system. These are summarized from Model 4 result as follows:

- Production throughput increased by 16.6 %. (Achieve targeted production rate).
- WIP decreased by 50.49 %.
- Resource cost decreased by 7.14 %.
- Shift time is reduced to be 11 hour per shift.
- Line efficiency increased by 22.26 %.
- Machine downtime decreased by 59.9 %.
- Most of the resources have usage rates more than 60% after improvements.

The simplified version of the results are viewed at Process Analyzer tool, Microsoft® Excel and animation while the full report which is in PDF version can be viewed after each simulation on ARENA®. It is also proven that the procurement of new machine and line balancing does increase the productivity of the line. The overall operation cost is also decreased with the change in performance parameters. To select the optimum performance measure, it requires the model to be built to function as similar as the actual system and with the specific enhancement it might have. The results verifies the main focus of the simulation model that is to vary the shift time and production rate based on market demand, to reduce loss due to downtime and to do line balancing. The company's main objective that is to maximize production output, while maintaining the quality, is also achieved.

5.2 Recommendation

There is a lot of room for improvement that could be done to this project. Since the main objective of this project is to improve the performance of the production line, most of the improvement should be focusing on the product and the resources itself. As a suggestion for study, the following scope should be taken into consideration:

- Changes in the current layout.
  - To eliminate waste in term of movement.
- Part supply analysis.
  - To ensure part supply is in flow as scheduled/as needed.
- Detailed cost analysis that includes operation costs and machine cost.
  - To determine profits/cost reduction achieved after each improvements.
- Conveyor speed regulation
  - Identify the optimum rate for conveyor motor's speed.
  - Determine the impact of regulating the speed.
- Analysis on the rework area
  - To minimize the rate of rework based on the defect rate, human/machine errors and other significant factors.
  - To determine any causal relationship between defect entity with the WIP value.

Another suggestion for future work is for the FYP committee to have official meeting with the chosen company to strongly clarify that the university will keep the data obtained as confidential. The significant purposes are to get faster approval from the company as well as any agreement on confidential issue and to make sure the projects run smoothly with sufficient data. This is proven by the author experience where the approval seeking consumes much time and delay to the project as most of the companies have huge concerns on data security.

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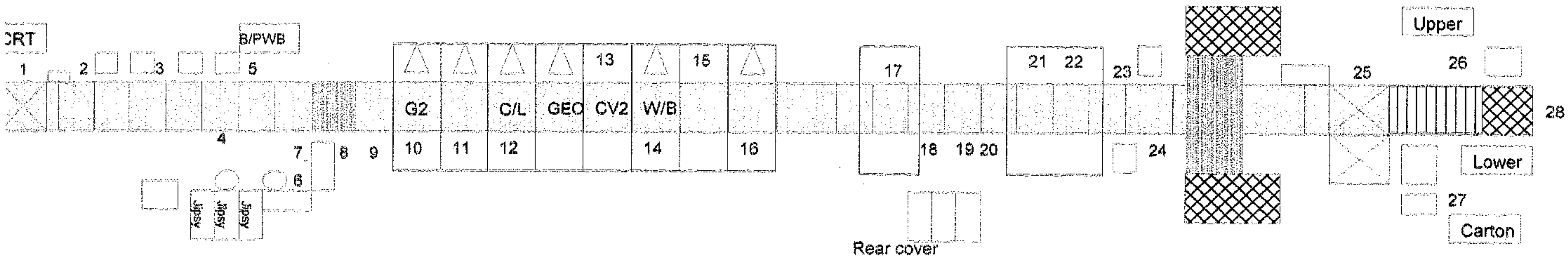
APPENDICES

APPENDIX 1

Actual line layout

LINE	B2	
CHASSIS	SMALL-XX	

MONTH	FEB 2006
MODEL	SMALL SERIES



NO	PROCESS	REMARKS
1	Input Beznet & CRT	M
2	Install DGC top	F
3	Install speaker + DY	M
4	Screw speaker	F
5	Screw CRT	M
6	Chassis 1	F
7	Chassis 2	F
8	Docking 1	F
9	Docking 2	F
10	G2 + HV check	F
11	Landing 1	F

NO	PROCESS	REMARKS
12	Corner landing	F
13	Convergence 2	F
14	Dressing	F
15	Touch up 1	F
16	AGC + Inspection	F
17	Touch up 2	F
18	Inward check	F
19	Install rear cover	M
20	Video check	F
21	Inspection 1	F
22	Inspection 2	F

NO	PROCESS	REMARKS
23	Inspection 3	F
24	Insulation test	F
25	Input set packing	M
26	Packing 1	M
27	Prepare carton	M
28	Direct vanning	M

power		*Indirect*		*Comment/Remark*
rator	28	Supervisor	1	
		Line leader	4	
		Technician	1	
AL	28	**TOTAL**	6	
GRAND TOTAL			34	

APPENDIX 2

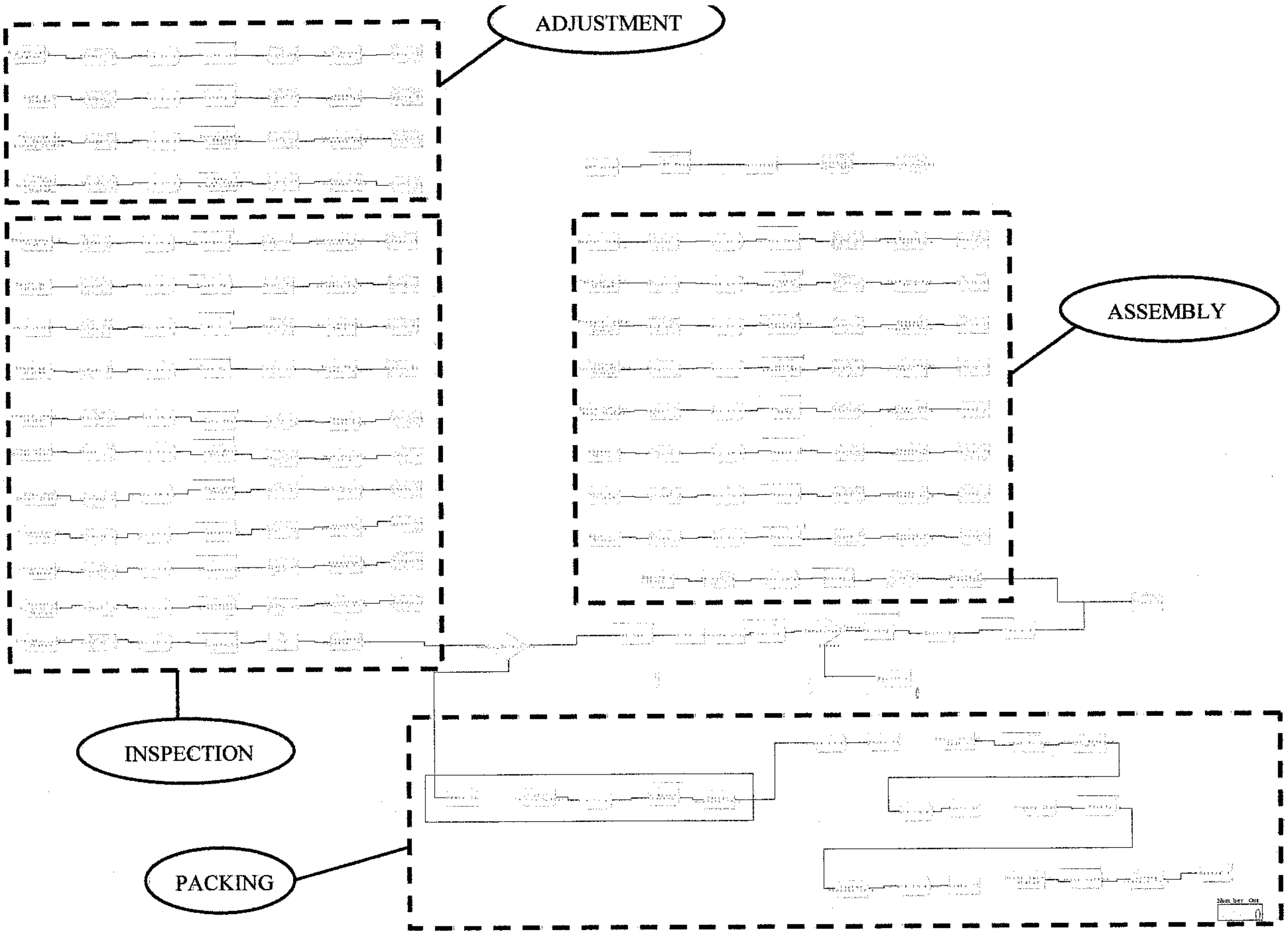
Process data

Process time [source: Siti Aishah Fadilullah, 2006, *Logbook, Student Industrial Internship Programme*]

No	Process	Minimum time (sec)	Maximum time (sec)	Average time (sec)	Activity allocation
1.	CRT Rising 1	6.06	7.55	6.98	Transfer
2.	Input Beznet + CRT	25.9	30.8	28.73	Value added
3.	Install tube + DGC + DY	29.9	35.7	33.19	Value added
4.	Prepare speaker	23.2	30.1	26.52	Value added
5.	Screw speaker	23.9	27.1	25.13	Value added
6.	Screw CRT	27.2	33.5	30.25	Value added
7.	Chassis 1	30.9	36.2	33.68	Value added
8.	Chassis 2	30.6	37.1	33.69	Value added
9.	Docking 1	33.5	35.9	34.6	Value added
10.	Docking 2	30.4	37.9	33.2	Value added
11.	G2 +HV check	33.9	36.4	35.05	Value added
12.	Landing + Convergence	39.6	42.2	40.89	Value added
13.	Corner landing	35.6	38.8	37.77	Value added
14.	White balance + Geometry	12.7	17.6	15.02	Value added
15.	Convergence 2	27.5	33.7	31.33	Value added
16.	Touch-up 1	25.6	32.1	28.87	Value added
17.	AGC	32.5	38.8	35.29	Value added
18.	Touch-up 2	32.5	39	35.41	Value added
19.	Inward check	32.7	39	35.61	Value added
20.	Rear cover	27.8	32.4	30.54	Value added
21.	Video check	25.9	30.2	27.7	Value added
22.	Inspection 1	18.6	25.6	21.9	Value added
23.	Inspection 2	27.2	32.5	30.15	Value added
24.	Inspection 3	32	35.5	33.89	Value added
25.	Insulation	24	29.5	26.98	Value added
26.	CRT Rising 2	6.06	7.55	6.98	Transfer
27.	Rework	586.80	3378	1764	Non value added
28.	CRT Rising 3	6.06	7.55	6.98	Transfer
29.	Prepare carton	27.1	32.6	29.87	Value added
30.	Input TV set	25.1	30.9	28.11	Value added
31.	Packing 1	18.6	22.1	20.57	Value added
32.	Direct vanning	10.4	13.2	12.20	Value added
TRANSFER + VA TIME		**782.98**	**929.05**	**887.08**	**28 VA**

APPENDIX 3

Nested model


ADJUSTMENT
ASSEMBLY
INSPECTION
PACKING

APPENDIX 4

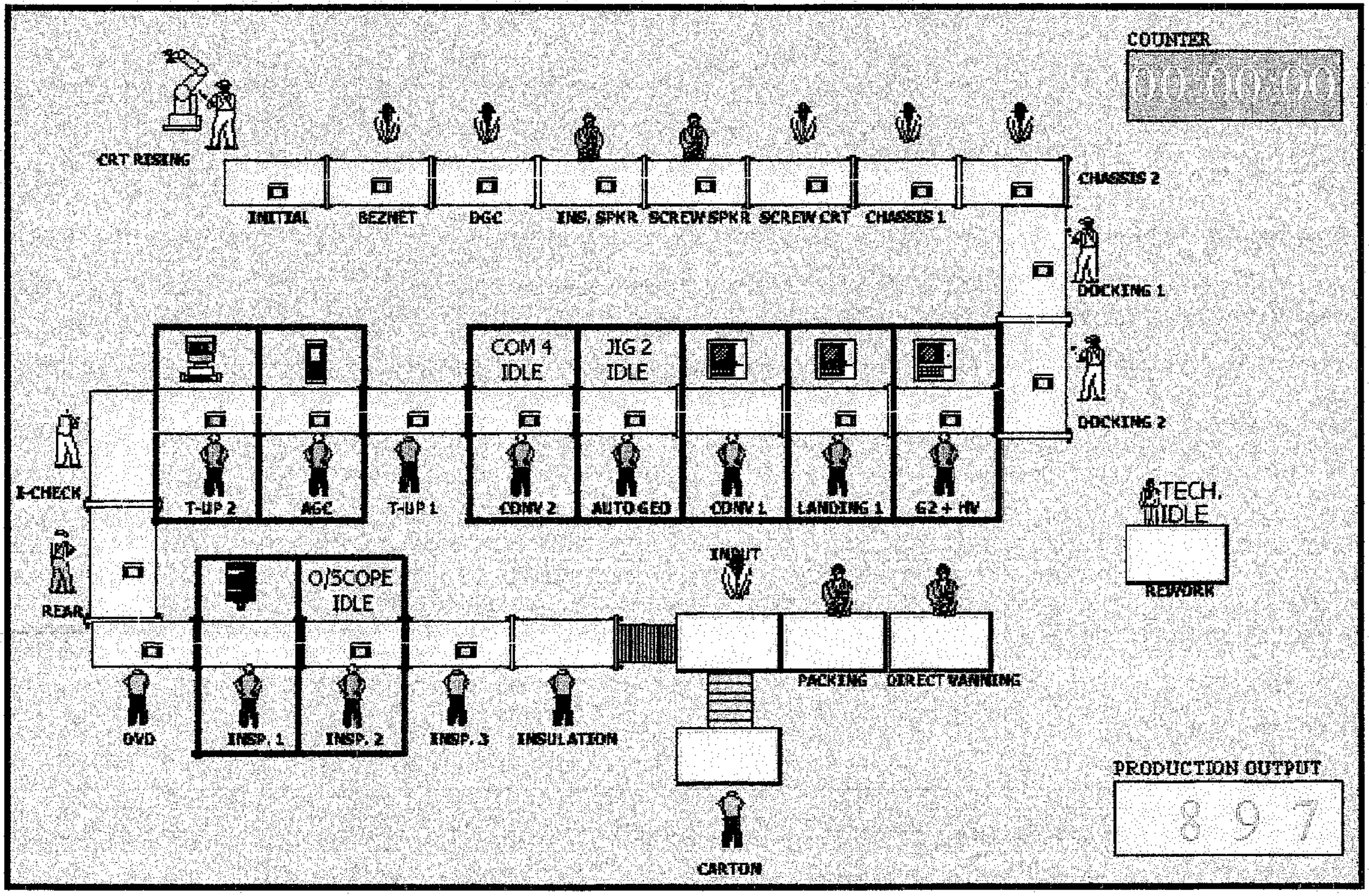
List of distribution

List of input distribution

No	Process	Distribution
1	Input Beznet + CRT	25.4 + 5.56 * BETA(0.929, 0.641)
2	Install tube + DGC + DY	29.3 + 6.73 * BETA(1.19, 0.877)
3	Prepare speaker	23 + WEIB(3.82, 1.43)
4	Screw speaker	23.6 + LOGN(1.56, 1.5)
5	Screw CRT & Set rising	UNIF(27, 34)
6	Chassis 1	TRIA(30.3, 34, 36.7)
7	Chassis 2	TRIA(30, 33.3, 37.8)
8	Docking 1	NORM(34.6, 0.765)
9	Docking 2	30 + GAMM(2.53, 1.27)
10	G2 +HV check	TRIA(33.5, 35.1, 36.7)
11	Landing 1	39.5 + 2.88 * BETA(0.766, 0.856)
12	Conv. 1_Corner landing	35.3 + 3.7 * BETA(1.49, 0.891)
13	White balance + Geometry	TRIA(12.2, 14.7, 18)
14	Convergence 2	27 + 7 * BETA(1.14, 0.754)
15	Touch-up 1	25 + GAMM(1.73, 2.24)
16	AGC	TRIA(32, 35.5, 39)
17	Touch-up 2	TRIA(32, 35.3, 39)
18	Inward check	NORM(35.6, 2.11)
19	Rear cover	27.3 + 5.55 * BETA(0.94, 0.685)
20	Video check	25.4 + WEIB(2.52, 1.63)
21	Inspection 1	TRIA(18, 21.7, 26)
22	Inspection 2	27 + 5.98 * BETA(0.727, 0.656)
23	Inspection 3	32 + 3.88 * BETA(0.442, 0.623)
24	Insulation	UNIF(24, 30)
25	Prepare carton	UNIF(27, 33)
26	Input	NORM(28.1, 1.86)
27	Packing 1	UNIF(18.3, 22.4)
28	Direct vanning	10.1 + 3.4 * BETA(0.894, 0.511)
29	CRT rising 1	TRIA(6, 7.23, 7.7)
30	CRT rising 2	TRIA(6, 7.23, 7.7)
31	CRT rising 3	TRIA(6, 7.23, 7.7)
32	Rework	9 + WEIB(22.3, 1.45)
33	Machine failure uptime	TRIA(12 , 12 , 13)

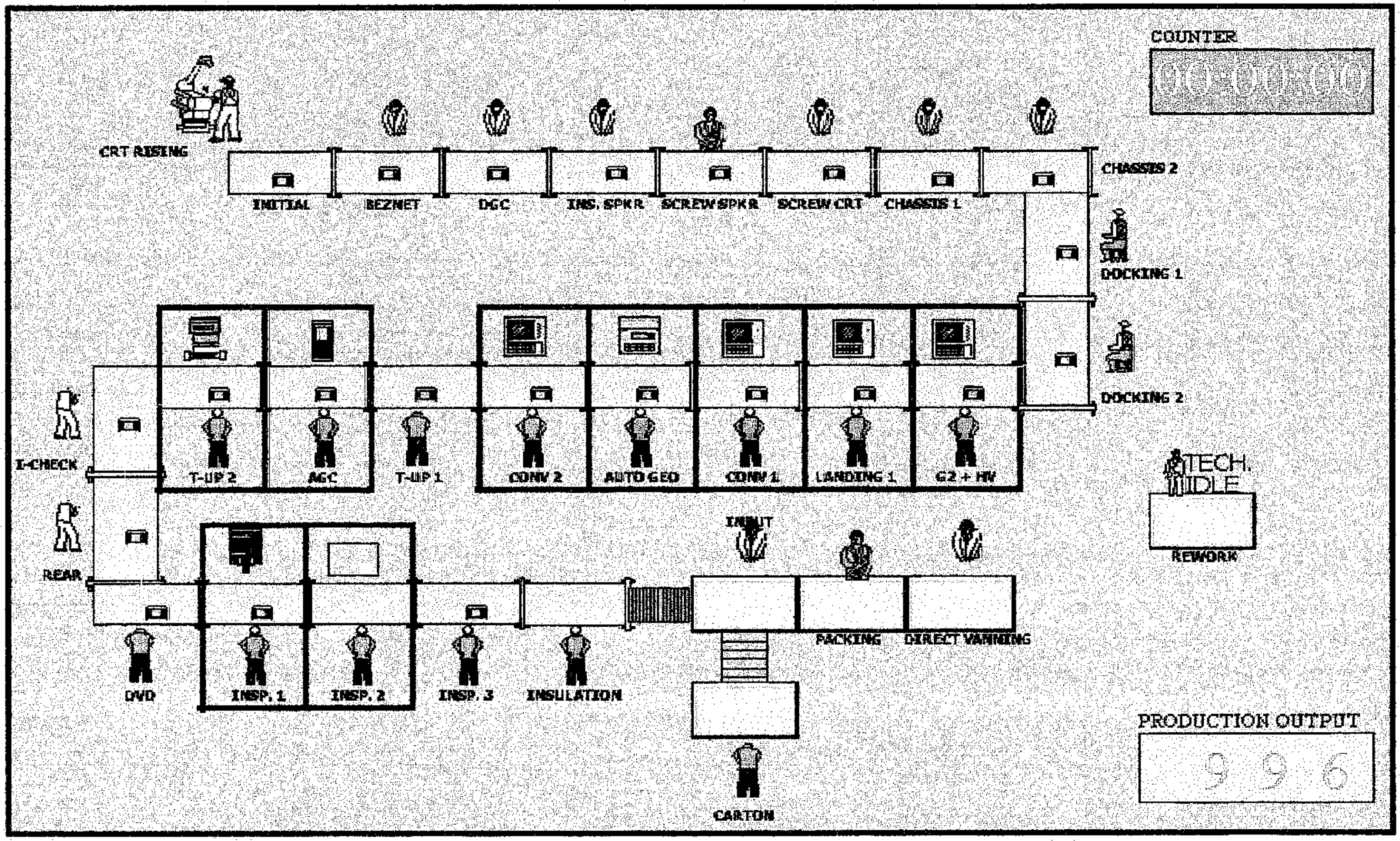
APPENDIX 5

Production output (Animation for Model 2)


COUNTER
00:00:00
CRT RISING
INITIAL
BEZNET
DGC
INS. SPKR
SCREW SPKR
SCREW CRT
CHASSIS 1
CHASSIS 2
DOCKING 1
DOCKING 2
COM 4
IDLE
JIG 2
IDLE
I-CHECK
T-UP 2
AGC
T-UP 1
CONV 2
AUTO GED
CONV 1
LANDING 1
G2 + HV
TECH.
IDLE
REWORK
REAR
O/SCOPE
IDLE
INPUT
PACKING
DIRECT VANNING
GVD
INSP. 1
INSP. 2
INSP. 3
INSULATION
PRODUCTION OUTPUT
8 9 7
CARTON

APPENDIX 6

Production output (Animation for Model 3)


COUNTER
00:00:00
CRT RISING
INITIAL
BEZNET
DGC
INS. SPKR
SCREW SPKR
SCREW CRT
CHASSIS 1
CHASSIS 2
DOCKING 1
DOCKING 2
I-CHECK
REAR
T-UP 2
AGC
T-UP 1
CONV 2
AUTO GEO
CONV 1
LANDING 1
G2 + HV
TECH.
IDLE
REWORK
INPUT
PACKING
DIRECT VANNING
DVD
INSP. 1
INSP. 2
INSP. 3
INSULATION
CARTON
PRODUCTION OUTPUT
9 9 6

APPENDIX 7

VBA codes

1. <u>VBA code for input process time user form.</u>

```
Private Sub CommandButton1_Click()
Dim m As Model
Dim theMod1 As Module
Dim theMod2 As Module
Dim theMod3 As Module
Dim theMod4 As Module
Dim theMod5 As Module
Dim theMod6 As Module
Dim theMod7 As Module
Dim theMod8 As Module
Dim theMod9 As Module
Dim theMod10 As Module
Dim theMod11 As Module
Dim theMod12 As Module
Dim theMod13 As Module
Dim theMod14 As Module
Dim theMod15 As Module
Dim theMod16 As Module
Dim theMod17 As Module
Dim theMod18 As Module
Dim theMod19 As Module
Dim theMod20 As Module
Dim theMod21 As Module
Dim theMod22 As Module
Dim theMod23 As Module
Dim theMod24 As Module
Dim theMod25 As Module
Dim theMod26 As Module
Dim theMod27 As Module
Dim theMod28 As Module
Dim a As Long
Dim b As Long
Dim c As Long
Dim d As Long
Dim e As Long
Dim f As Long
Dim g As Long
Dim h As Long
Dim i As Long
Dim j As Long
Dim k As Long
Dim l As Long
Dim n As Long
```

```
Dim o As Long
Dim p As Long
Dim q As Long
Dim r As Long
Dim s As Long
Dim t As Long
Dim u As Long
Dim v As Long
Dim w As Long
Dim x As Long
Dim y As Long
Dim z As Long
Dim aa As Long
Dim ab As Long
Dim ac As Long
Set m = ThisDocument.Model
'..................................................................................................
a = m.Modules.Find(smFindTag, "Process1")
Set theMod1 = m.Modules(a)
theMod1.Data("Value") = TextBox1.value
b = m.Modules.Find(smFindTag, "Process2")
Set theMod2 = m.Modules(b)
theMod2.Data("Value") = TextBox2.value
c = m.Modules.Find(smFindTag, "Process3")
Set theMod3 = m.Modules(c)
theMod3.Data("Value") = TextBox3.value
d = m.Modules.Find(smFindTag, "Process4")
Set theMod4 = m.Modules(d)
theMod4.Data("Value") = TextBox4.value
e = m.Modules.Find(smFindTag, "Process5")
Set theMod5 = m.Modules(e)
theMod5.Data("Value") = TextBox5.value
f = m.Modules.Find(smFindTag, "Process6")
Set theMod6 = m.Modules(f)
theMod6.Data("Value") = TextBox6.value
g = m.Modules.Find(smFindTag, "Process7")
Set theMod7 = m.Modules(g)
theMod7.Data("Value") = TextBox7.value
h = m.Modules.Find(smFindTag, "Process8")
Set theMod8 = m.Modules(h)
theMod8.Data("Value") = TextBox8.value
i = m.Modules.Find(smFindTag, "Process9")
Set theMod9 = m.Modules(i)
theMod9.Data("Value") = TextBox9.value
j = m.Modules.Find(smFindTag, "Process10")
Set theMod10 = m.Modules(j)
```

```
theMod10.Data("Value") = TextBox10.value
k = m.Modules.Find(smFindTag, "Process11")
Set theMod11 = m.Modules(k)
theMod11.Data("Value") = TextBox11.value
l = m.Modules.Find(smFindTag, "Process12")
Set theMod12 = m.Modules(l)
theMod12.Data("Value") = TextBox12.value
n = m.Modules.Find(smFindTag, "Process13")
Set theMod13 = m.Modules(n)
theMod13.Data("Value") = TextBox13.value
o = m.Modules.Find(smFindTag, "Process14")
Set theMod14 = m.Modules(o)
theMod14.Data("Value") = TextBox14.value
p = m.Modules.Find(smFindTag, "Process15")
Set theMod15 = m.Modules(p)
theMod15.Data("Value") = TextBox15.value
q = m.Modules.Find(smFindTag, "Process16")
Set theMod16 = m.Modules(q)
theMod16.Data("Value") = TextBox16.value
r = m.Modules.Find(smFindTag, "Process17")
Set theMod17 = m.Modules(r)
theMod17.Data("Value") = TextBox17.value
s = m.Modules.Find(smFindTag, "Process18")
Set theMod18 = m.Modules(s)
theMod18.Data("Value") = TextBox18.value
t = m.Modules.Find(smFindTag, "Process19")
Set theMod19 = m.Modules(t)
theMod19.Data("Value") = TextBox19.value
u = m.Modules.Find(smFindTag, "Process20")
Set theMod20 = m.Modules(u)
theMod20.Data("Value") = TextBox20.value
v = m.Modules.Find(smFindTag, "Process21")
Set theMod21 = m.Modules(v)
theMod21.Data("Value") = TextBox21.value
w = m.Modules.Find(smFindTag, "Process22")
Set theMod22 = m.Modules(w)
theMod22.Data("Value") = TextBox22.value
x = m.Modules.Find(smFindTag, "Process23")
Set theMod23 = m.Modules(x)
theMod23.Data("Value") = TextBox23.value
y = m.Modules.Find(smFindTag, "Process24")
Set theMod24 = m.Modules(y)
theMod24.Data("Value") = TextBox24.value
z = m.Modules.Find(smFindTag, "Process25")
Set theMod25 = m.Modules(z)

theMod25.Data("Value") = TextBox25.value
```

```
aa = m.Modules.Find(smFindTag, "Process26")
Set theMod26 = m.Modules(aa)
theMod26.Data("Value") = TextBox26.value
ab = m.Modules.Find(smFindTag, "Process27")
Set theMod27 = m.Modules(ab)
theMod27.Data("Value") = TextBox27.value
ac = m.Modules.Find(smFindTag, "Process28")
Set theMod28 = m.Modules(ac)
theMod28.Data("Value") = TextBox28.value
Me.Hide 'to hide the userform after click ok

End Sub
```

2. VBA code for welcome form and abort simulation form.

```
Private Sub CommandButton1_Click()
Dim m As Model 'Define variables used in
Dim s As SIMAN 'the VBA logic.
Set m = ThisDocument.Model 'm is defined
                    'as this particular
                    'model.
Set s = m.SIMAN
UserForm2.hide 'Get rid of the User Form
            'when the abort button is
            'clicked.
m.End       'End the model run.
End Sub

Private Sub CommandButton2_Click()
Dim m As Model 'Define variables used in
Dim s As SIMAN 'the VBA logic.
Set m = ThisDocument.Model ' m is defined
Set s = m.SIMAN          'as this particular
                    'model.
UserForm2.hide 'Get rid of the User Form
            'when the abort button is
            'clicked.
m.Go        'Continue the model run
End Sub

Private Sub Label1_Click()

End Sub

Private Sub UserForm_Click()

End Sub
```

APPENDIX 8

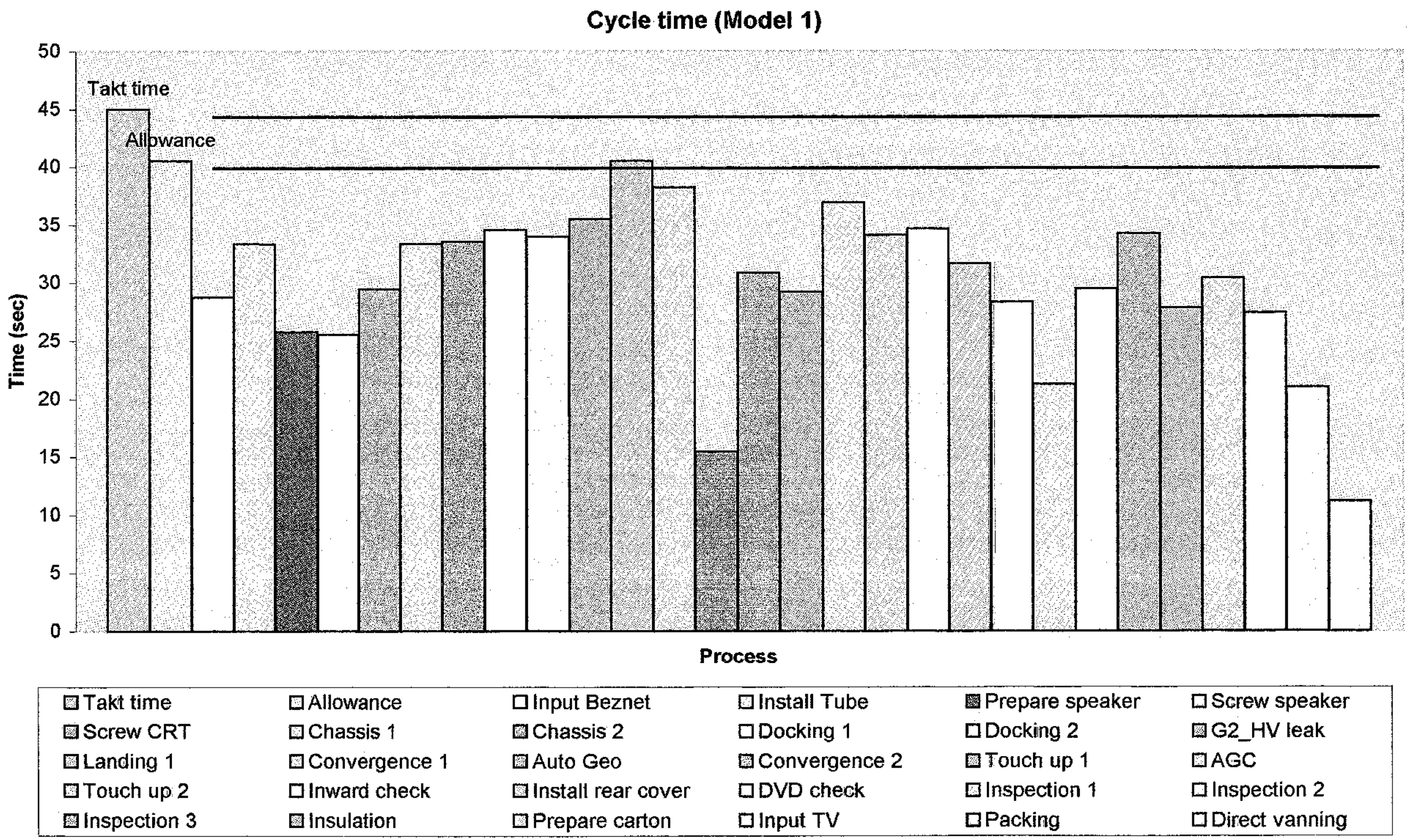
Exported data and charts at Microsoft® Excel

CYCLE TIME (MODEL 1)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1
		28.73	35.73	23.21	25.66	27.19	36.19	30.59	34.61
		25.93	35.73	30.15	25.13	28.88	33.68	34.63	34.6
		29.04	29.86	26.52	25.13	28.88	32.96	33.69	34.6
		28.73	33.19	25.44	25.13	30.53	33.52	37.12	34.6
		30.02	35.73	25.92	27.12	32.16	32.96	34.63	33.87
		30.02	29.86	23.21	25.13	29.22	30.85	30.59	35.09
45	**40.5**	**28.745**	**33.35**	**25.74166667**	**25.55**	**29.47666667**	**33.36**	**33.541667**	**34.56166667**

Docking 2	G2_HV leak	Landing 1	Convergence	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check
34.57	34.86	42.17	38.5	17.58	31.33	31.21	35.29	38.96	37.55
32.52	34.95	40.89	37.77	15.02	27.54	27.52	35.29	35.51	35.61
30.66	35.05	39.77	37.77	15.23	33.69	27.52	38.75	32.52	34.03
30.39	35.21	40.09	38.5	15.02	31.33	31.21	34.85	32.52	32.66
37.86	36.44	40.09	38.5	14.42	33.69	25.65	38.75	32.52	34.03
37.86	36.44	40.09	38.5	15.23	27.54	32.12	38.75	32.52	34.03
33.976667	**35.491667**	**40.5166667**	**38.2566667**	**15.41666667**	**30.85333333**	**29.205**	**36.9466667**	**34.091667**	**34.65166667**

Rear cover	DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
32.05	27.29	25.63	28.88	35.52	26.98	28.85	25.06	22.09	12.53
30.54	30.23	22.71	30.56	35.52	29.53	27.06	26.95	21.5	10.36
32.41	30.23	20.99	32.45	34.63	26.98	32.56	28.11	19.04	10.36
32.41	25.89	20.99	28.88	35.52	26.98	28.85	28.11	22.09	10.36
32.05	27.7	18.63	27.23	32.01	29.53	32.56	27.96	20.57	10.36
30.54	28.56	18.63	28.88	32.12	26.98	32.56	28.11	20.57	13.09
31.666667	**28.316667**	**21.2633333**	**29.48**	**34.22**	**27.83**	**30.40666667**	**27.3833333**	**20.976667**	**11.17666667**

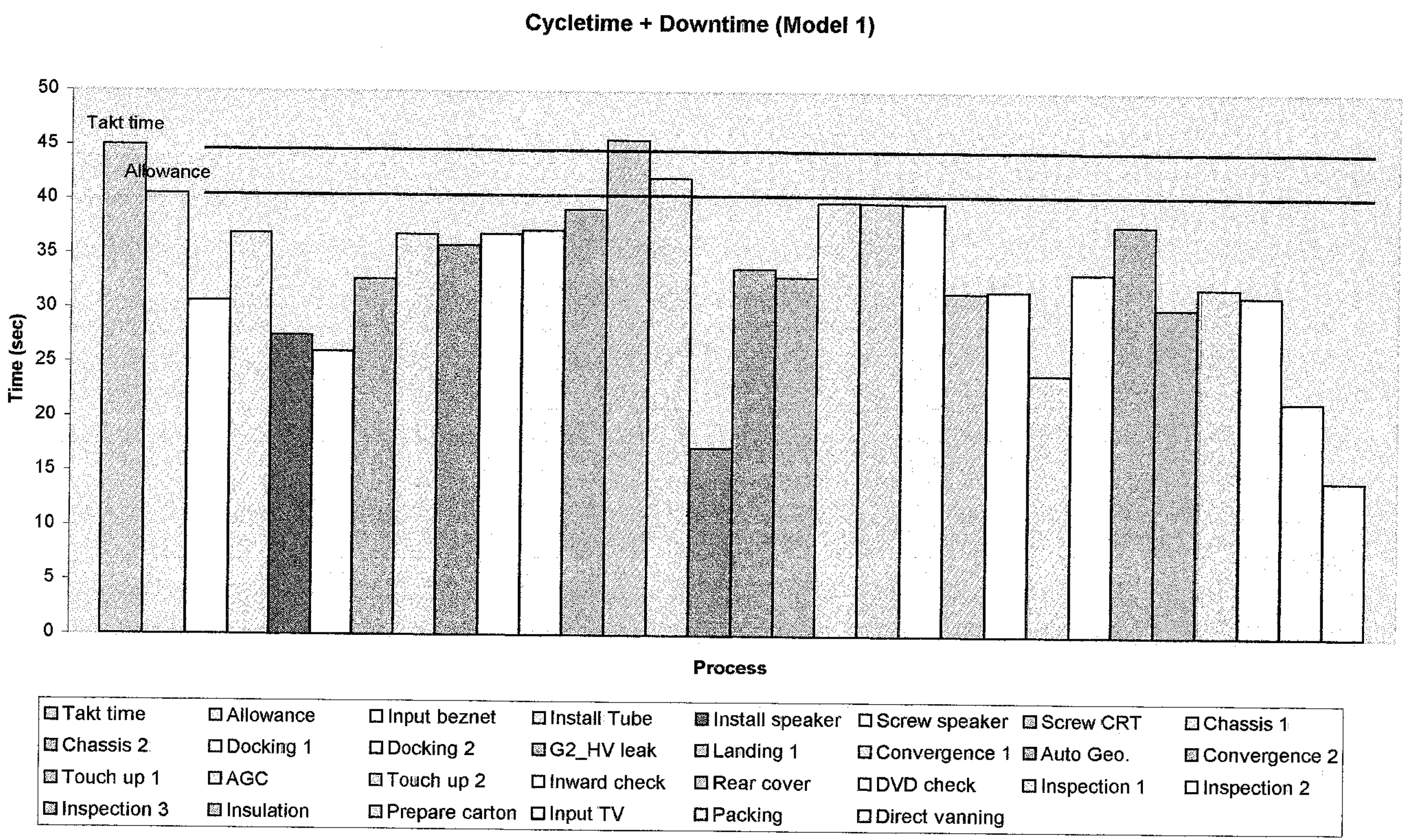

Cycle time (Model 1)
Time (sec)
50
45
40
35
30
25
20
15
10
5
0
Takt time
Allowance
Process
Takt time
Allowance
Input Beznet
Install Tube
Prepare speaker
Screw speaker
Screw CRT
Chassis 1
Chassis 2
Docking 1
Docking 2
G2_HV leak
Landing 1
Convergence 1
Auto Geo
Convergence 2
Touch up 1
AGC
Touch up 2
Inward check
Install rear cover
DVD check
Inspection 1
Inspection 2
Inspection 3
Insulation
Prepare carton
Input TV
Packing
Direct vanning

CYCLE TIME + DOWNTIME (MODEL 1)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1
		31.12	37.22	27.08	25.87	32.66	36.59	35.89	36.92
		30.76	36.82	26.99	25.87	33.15	36.89	35.61	36.92
		30.08	36.82	27.4	25.87	32.66	36.89	35.89	36.66
		30.08	36.78	28.13	26.54	32.66	36.92	35.75	36.92
		30.76	36.82	27.08	25.87	32.19	36.59	35.75	36.94
		31.08	36.78	28.13	26.13	32.66	36.89	35.75	36.66
45	**40.5**	**30.6466667**	**36.8733333**	**27.46833333**	**26.025**	**32.66333333**	**36.795**	**35.773333**	**36.83666667**

Docking 2	G2_HV leak	Landing 1	Convergence	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check
37.36	38.97	45.86	42.04	17.44	33.71	33.15	39.89	39.46	39.74
37.29	39.36	45.49	42.04	17.44	33.24	32.77	39.89	40.04	39.82
36.98	39.36	45.49	42.04	17.12	33.24	33.15	39.55	40.04	39.66
36.98	39.05	45.49	42.04	17.12	34.18	32.96	39.89	39.46	39.82
37.29	39.05	45.49	42.04	17.44	33.71	32.77	39.89	39.75	39.74
37.29	38.97	45.49	42.04	16.8	34.18	32.96	39.89	40.04	39.74
37.198333	**39.126667**	**45.5516667**	**42.04**	**17.22666667**	**33.71**	**32.96**	**39.8333333**	**39.798333**	**39.75333333**

Rear cover	DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
31.47	31.77	23.97	33.15	37.75	30.23	32.23	31.49	21.71	14.32
31.83	32.01	23.97	33.51	37.75	30.07	31.89	30.75	21.71	14.32
31.47	31.77	24.05	33.51	37.64	30.23	31.89	31.49	21.71	14.17
31.47	31.53	24.05	33.51	37.75	30.07	31.89	31.49	20.99	14.32
31.83	31.53	24.01	33.33	37.75	29.91	32.23	31.49	21.71	14.47
31.11	31.53	24.05	33.15	37.75	30.23	32.06	31.12	21.71	14.47
31.53	**31.69**	**24.0166667**	**33.36**	**37.73166667**	**30.12333333**	**32.03166667**	**31.305**	**21.59**	**14.345**

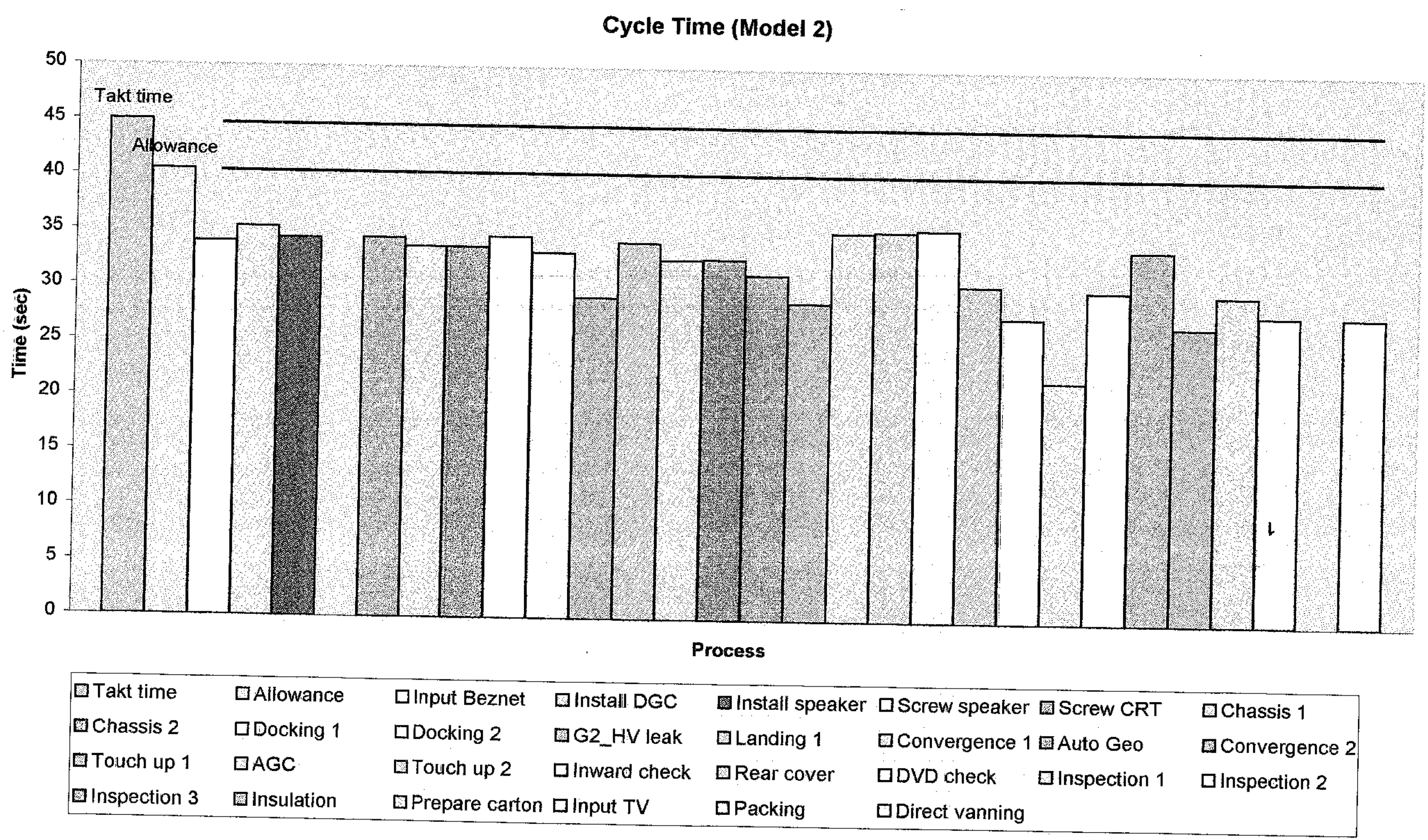

Cycletime + Downtime (Model 1)
Time (sec)
50
45
40
35
30
25
20
15
10
5
0
Takt time
Allowance
Process
Takt time
Allowance
Input beznet
Install Tube
Install speaker
Screw speaker
Screw CRT
Chassis 1
Chassis 2
Docking 1
Docking 2
G2_HV leak
Landing 1
Convergence 1
Auto Geo.
Convergence 2
Touch up 1
AGC
Touch up 2
Inward check
Rear cover
DVD check
Inspection 1
Inspection 2
Inspection 3
Insulation
Prepare carton
Input TV
Packing
Direct vanning

CYCLE TIME (MODEL 2)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
		33.98	35.31	34.36	0	34.45	33.68	33.69	34.6
45	**40.5**	**33.98**	**35.31**	**34.36**	**0**	**34.45**	**33.68**	**33.69**	**34.6**

Docking 2	G2_HV leak	Landing 1	Convergence	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	29.14	34.16	32.67	32.76	31.33	28.87	35.29	35.41	35.61
33.2	**29.14**	**34.16**	**32.67**	**32.76**	**31.33**	**28.87**	**35.29**	**35.41**	**35.61**

Rear cover	DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	27.7	21.9	30.15	33.89	26.98	29.87	28.11	0	28.05
30.54	**27.7**	**21.9**	**30.15**	**33.89**	**26.98**	**29.87**	**28.11**	**0**	**28.05**

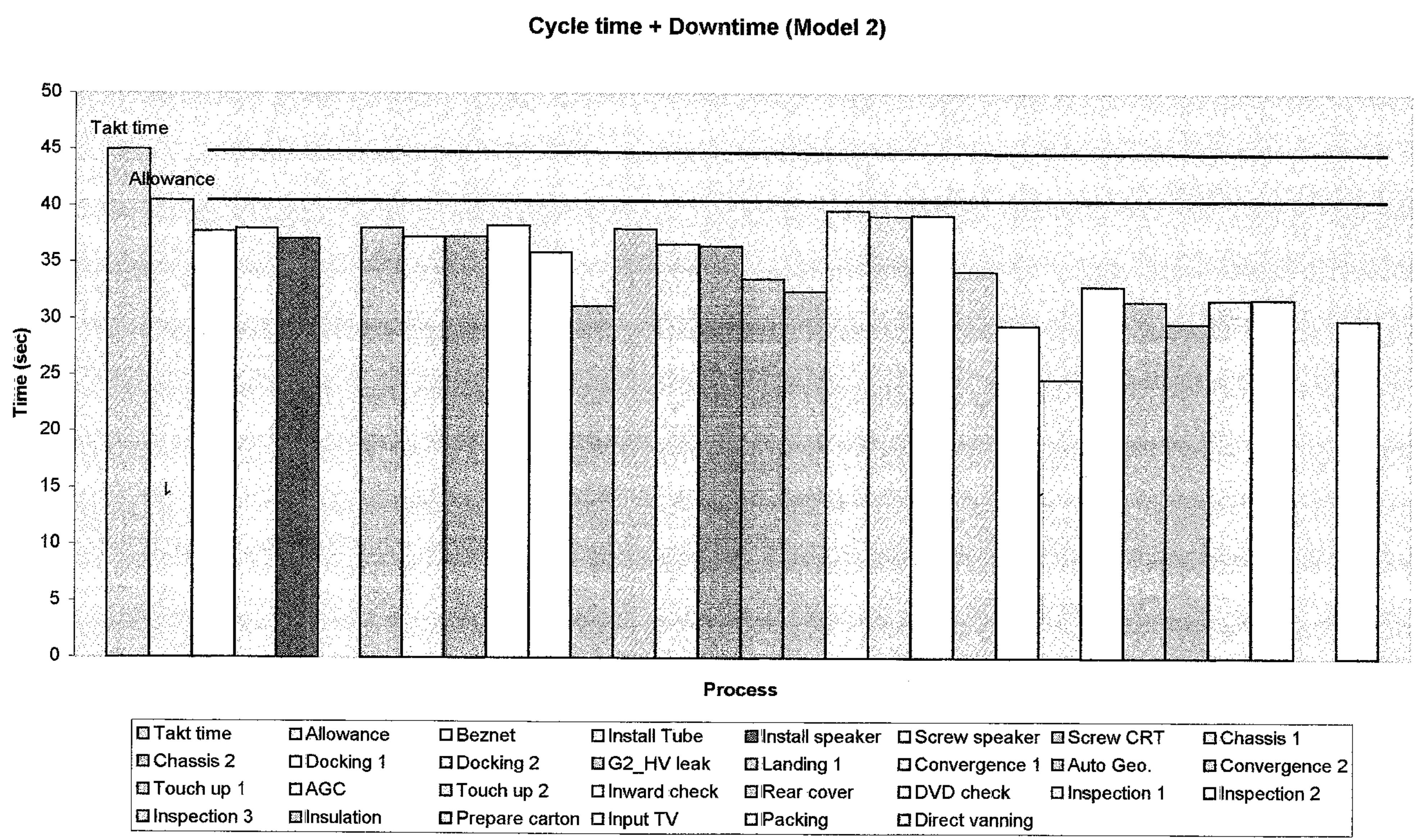

Cycle Time (Model 2)
Time (sec)
Process
50
45
40
35
30
25
20
15
10
5
0
Takt time
Allowance
Takt time
Allowance
Input Beznet
Install DGC
Install speaker
Screw speaker
Screw CRT
Chassis 1
Chassis 2
Docking 1
Docking 2
G2_HV leak
Landing 1
Convergence 1
Auto Geo
Convergence 2
Touch up 1
AGC
Touch up 2
Inward check
Rear cover
DVD check
Inspection 1
Inspection 2
Inspection 3
Insulation
Prepare carton
Input TV
Packing
Direct vanning

CYCLE TIME + DOWNTIME (MODEL 2)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1
		37.28	37.93	37.19	0	38.05	37.28	37.54	38.35
		37.84	38.05	37.19	0	38.05	37.11	37.04	38.35
		37.84	37.99	36.91	0	38.17	37.28	37.29	38.2
		37.84	37.93	37.19	0	37.93	37.28	37.04	38.05
		37.84	37.93	36.91	0	38.17	37.28	37.54	38.35
		37.84	38.05	37.19	0	37.93	37.28	37.29	38.35
45	**40.5**	**37.7466667**	**37.98**	**37.09666667**	**0**	**38.05**	**37.251667**	**37.29**	**38.275**

Docking 2	G2_HV leak	Landing 1	Convergence	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check
35.72	31	38.01	36.74	36.47	33.59	32.67	40.01	39.25	39.15
36.08	31.26	38.13	36.56	36.33	33.59	32.29	38.9	39.25	39.29
35.9	31	37.89	36.65	36.47	33.59	32.67	40.01	38.99	39.22
35.72	31.13	37.89	36.56	36.47	33.41	32.48	40.01	39.12	39.22
35.9	31	37.89	36.74	36.47	33.59	32.29	40.01	38.99	39.22
36.08	31.26	38.13	36.56	36.61	33.77	32.48	38.9	39.12	39.22
35.9	**31.1083333**	**37.99**	**36.635**	**36.47**	**33.59**	**32.48**	**39.64**	**39.12**	**39.22**

Rear cover	DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
34.15	29.42	24.75	32.94	31.55	29.57	31.49	31.55	0	29.95
34.15	29.42	24.75	32.94	31.55	29.57	31.67	31.89	0	29.95
34.34	29.51	24.64	32.86	31.55	29.57	31.85	31.89	0	29.95
34.15	29.51	24.64	32.94	31.55	29.69	31.85	31.72	0	29.95
34.15	29.42	24.53	32.94	31.55	29.81	31.49	31.89	0	29.86
34.34	29.42	24.64	32.86	31.79	29.57	31.85	31.72	0	29.95
34.21333	**29.45**	**24.6583333**	**32.9133333**	**31.59**	**29.63**	**31.7**	**31.776667**	**0**	**29.935**


Cycle time + Downtime (Model 2)
Takt time
Allowance
Time (sec)
50
45
40
35
30
25
20
15
10
5
0
Process
Takt time
Allowance
Beznet
Install Tube
Install speaker
Screw speaker
Screw CRT
Chassis 1
Chassis 2
Docking 1
Docking 2
G2_HV leak
Landing 1
Convergence 1
Auto Geo.
Convergence 2
Touch up 1
AGC
Touch up 2
Inward check
Rear cover
DVD check
Inspection 1
Inspection 2
Inspection 3
Insulation
Prepare carton
Input TV
Packing
Direct vanning

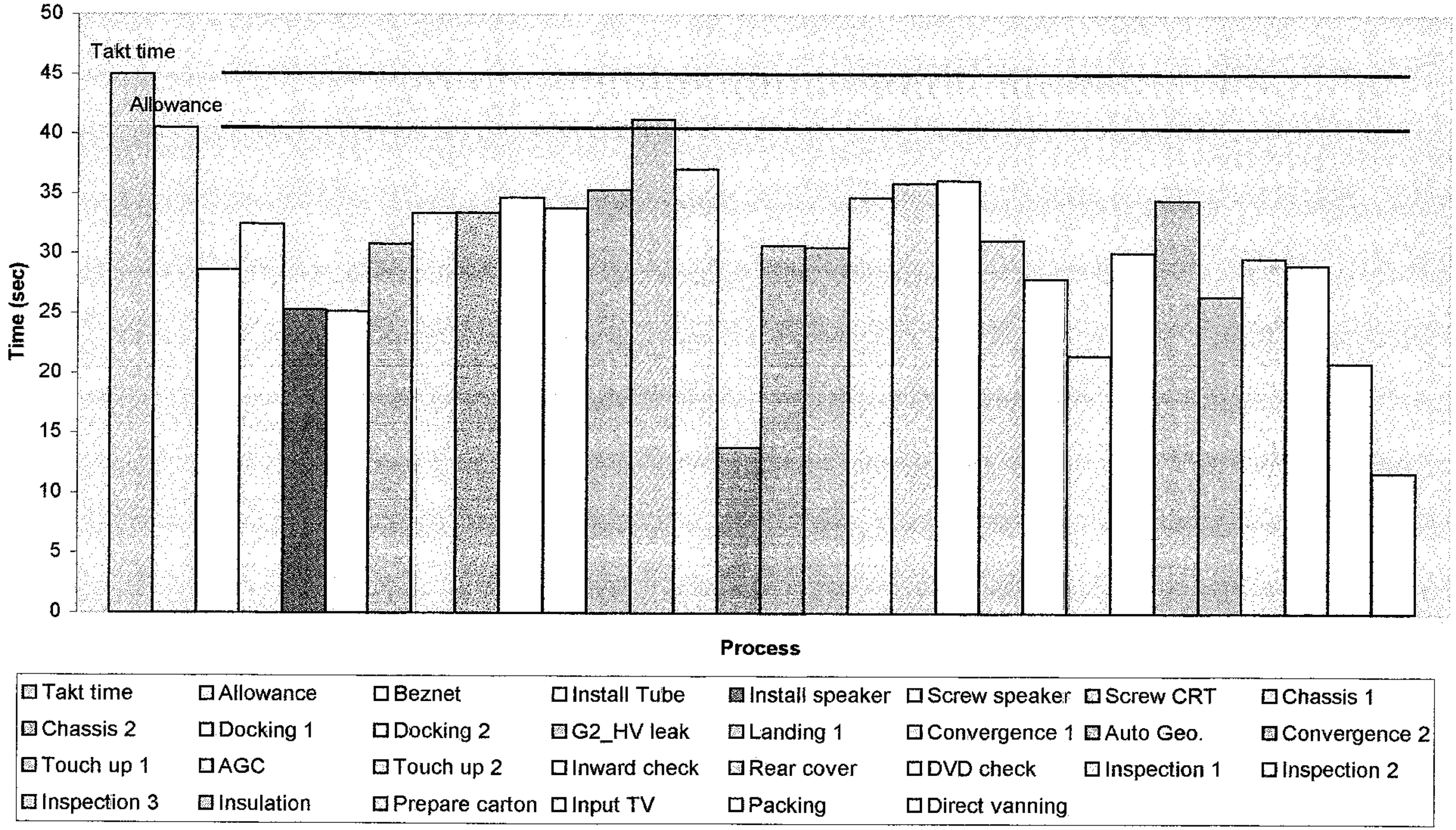
CYCLE TIME (MODEL 3)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1	Docking 2
		29.04	29.86	25.44	25.13	27.19	33.68	33.46	33.55	37.86
		27.88	32.01	26.52	24.79	33.52	33.52	33.46	34.6	37.86
		28.73	35.73	25.44	25.66	33.52	33.68	33.69	34.6	33.2
		28.73	33.21	27.88	24.13	29.22	32.96	33.69	35.88	30.66
		28.73	32.01	23.21	25.66	32.16	33.52	33.69	35.88	30.66
		28.73	32.01	23.21	25.66	29.22	32.96	32.65	33.55	32.52
45	**40.5**	**28.64**	**32.4716667**	**25.28333333**	**25.17166667**	**30.805**	**33.386667**	**33.44**	**34.67667**	**33.79333**

G2_HV leak	Landing 1	Convergence	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check	Rear cover
34.86	41.53	35.62	12.72	30.22	31.21	38.75	38.96	34.85	32.05
34.95	40.89	38.09	14.95	31.33	32.12	35.02	35.88	37.55	32.41
35.21	40.89	37.77	14.95	31.68	28.87	32.52	34.45	34.03	27.8
35.21	40.89	37.77	12.72	27.54	28.87	32.52	35.88	38.96	32.05
35.21	40.89	35.62	14.95	30.22	31.21	34.85	35.88	32.66	30.54
36.44	42.17	37.77	12.72	33.52	31.21	34.85	34.45	38.96	32.05
35.313333	**41.21**	**37.1066667**	**13.835**	**30.75166667**	**30.58166667**	**34.75166667**	**35.916667**	**36.16833333**	**31.15**

DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
27.7	21.54	30.56	35.52	24.03	27.06	30.85	21.57	10.36
27.7	21.54	27.23	33.89	25.67	28.88	30.85	21.57	10.36
30.23	22.71	32.45	32.12	26.98	29.87	30.85	20.57	12.98
30.23	20.99	28.88	34.63	26.98	32.56	28.11	22.09	12.2
25.89	21.54	31.89	35.52	29.53	29.87	26.95	20.57	12.53
25.89	20.99	29.85	35.52	25.67	29.87	26.95	19.04	12.2
27.94	**21.551667**	**30.1433333**	**34.5333333**	**26.47666667**	**29.685**	**29.09333333**	**20.901667**	**11.77166667**

Cycle time (Model 3)

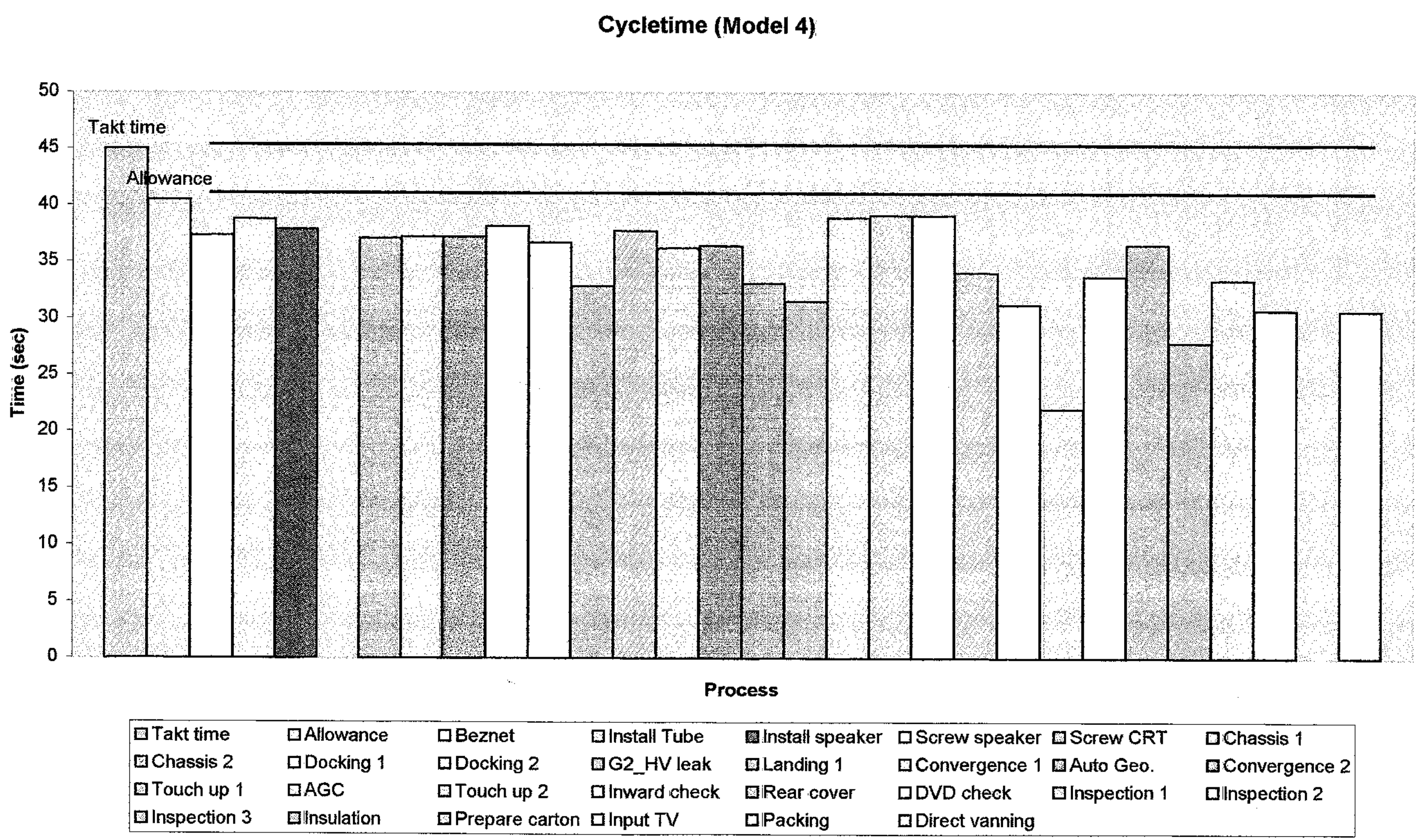


CYCLE TIME (MODEL 4)

Takt time	Allowance	Beznet	Install Tube	Install speaker	Screw speaker	Screw CRT	Chassis 1	Chassis 2	Docking 1
		37.53	38.75	37.78	0	37.09	37.2	37.15	38.21
		37.32	38.73	37.78	0	37.09	37.18	37.3	38.21
		37.32	38.81	37.99	0	37.18	37.2	37.21	38.13
		37.32	38.73	37.78	0	36.95	37.2	37.3	38.14
		37.32	38.75	37.99	0	37.18	37.2	37.15	38.14
		37.32	38.73	37.78	0	36.95	37.2	37.21	38.21
45	**40.5**	**37.355**	**38.75**	**37.85**	**0**	**37.07333333**	**37.196667**	**37.22**	**38.17333**

Docking 2	G2_HV leak	Landing 1	Convergence 1	Auto Geo.	Convergence 2	Touch up 1	AGC	Touch up 2	Inward check
36.67	32.79	37.73	36.26	36.4	33.14	31.54	38.91	39.13	39.11
36.81	32.78	37.71	36.27	36.45	33.14	31.55	38.93	39.15	39.15
36.73	32.89	37.68	36.24	36.45	33.14	31.54	38.96	39.13	39.16
36.71	32.82	37.8	36.27	36.4	33.14	31.52	38.96	39.08	39.16
36.73	32.89	37.8	36.19	36.45	33.14	31.47	38.96	39.13	39.14
36.81	32.79	37.71	36.27	36.38	33.12	31.52	38.93	39.12	39.16
36.743333	**32.8266667**	**37.738333**	**36.25**	**36.42166667**	**33.13666667**	**31.52333333**	**38.941667**	**39.123333**	**39.14667**

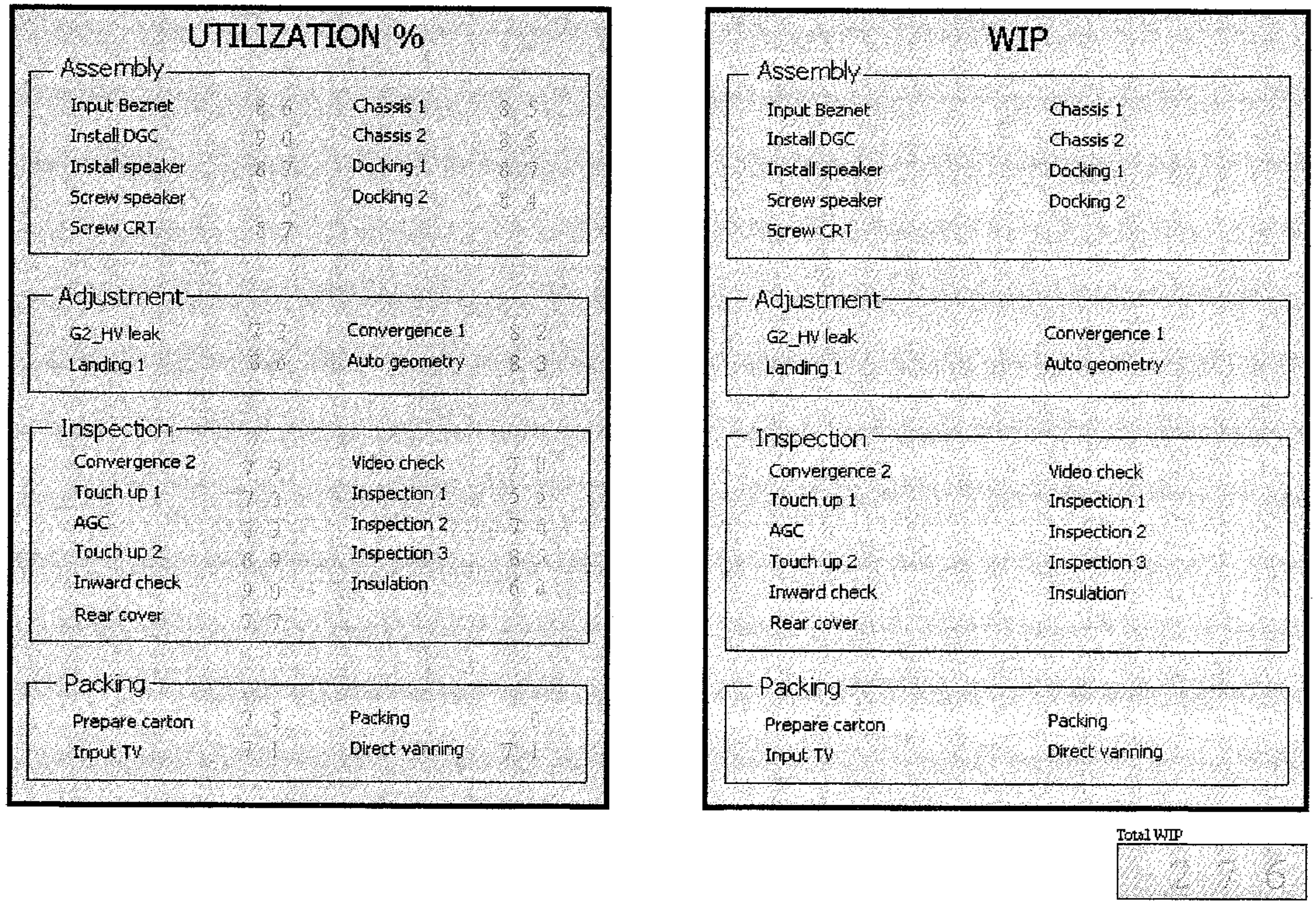
Rear cover	DVD check	Inspection 1	Inspection 2	Inspection 3	Insulation	Prepare carton	Input TV	Packing	Direct vanning
34.07	31.24	21.98	33.75	36.51	27.85	33.44	30.81	0	30.68
34.07	31.25	21.98	33.75	36.51	27.85	33.41	30.75	0	30.68
34.04	31.23	22	33.74	36.51	27.85	33.44	30.72	0	30.68
34.11	31.23	22	33.75	36.51	27.86	33.42	30.81	0	30.73
34.11	31.24	22.06	33.75	36.5	27.83	33.44	30.72	0	30.7
34.04	31.24	22	33.74	36.58	27.85	33.42	30.81	0	30.68
34.073333	**31.2383333**	**22.003333**	**33.74666667**	**36.52**	**27.84833333**	**33.42833333**	**30.77**	**0**	**30.69167**



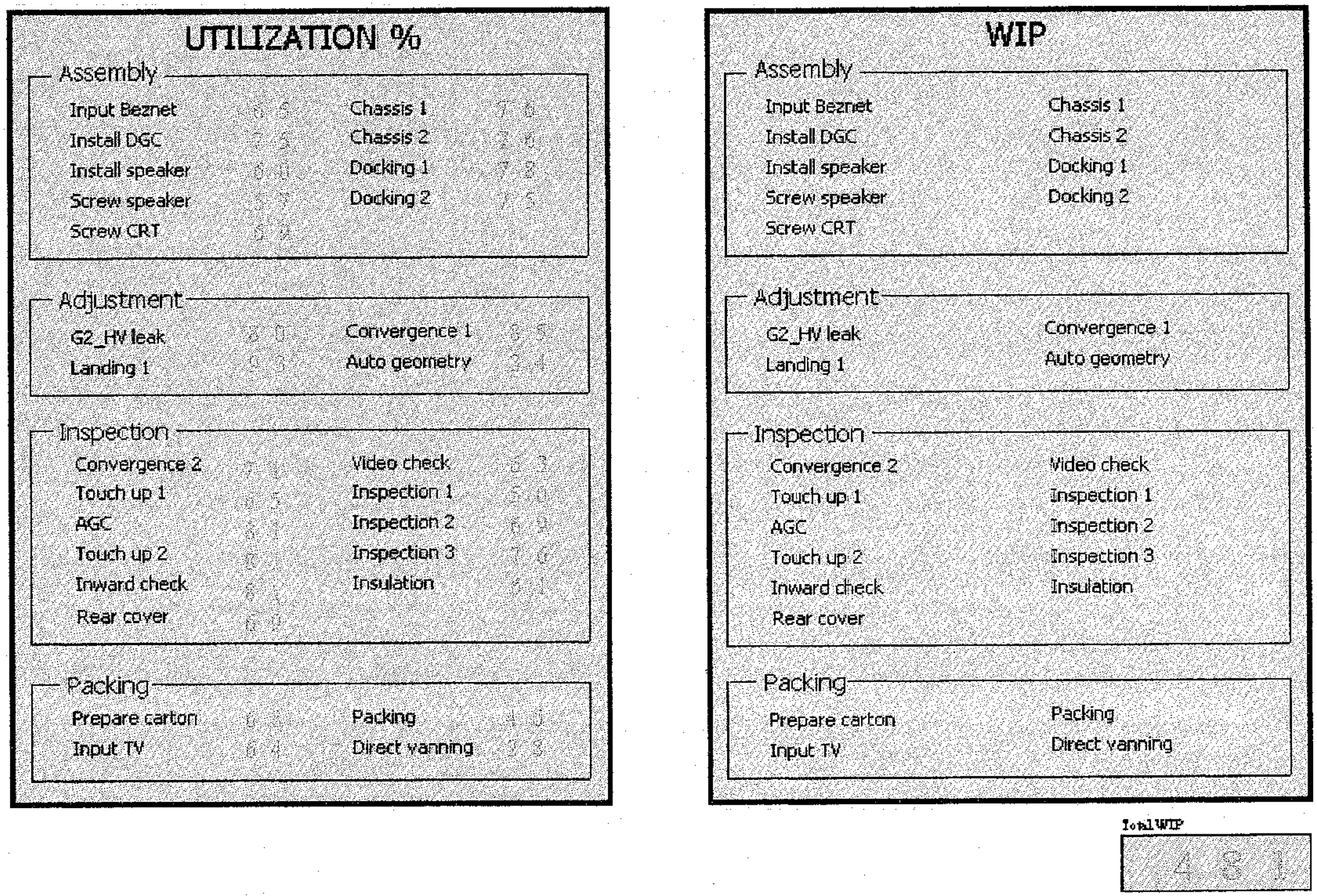
Cycletime (Model 4)
Takt time
Allowance
50
45
40
35
30
25
20
15
10
5
0
Time (sec)
Process
Takt time
Allowance
Beznet
Install Tube
Install speaker
Screw speaker
Screw CRT
Chassis 1
Chassis 2
Docking 1
Docking 2
G2_HV leak
Landing 1
Convergence 1
Auto Geo.
Convergence 2
Touch up 1
AGC
Touch up 2
Inward check
Rear cover
DVD check
Inspection 1
Inspection 2
Inspection 3
Insulation
Prepare carton
Input TV
Packing
Direct vanning

APPENDIX 9

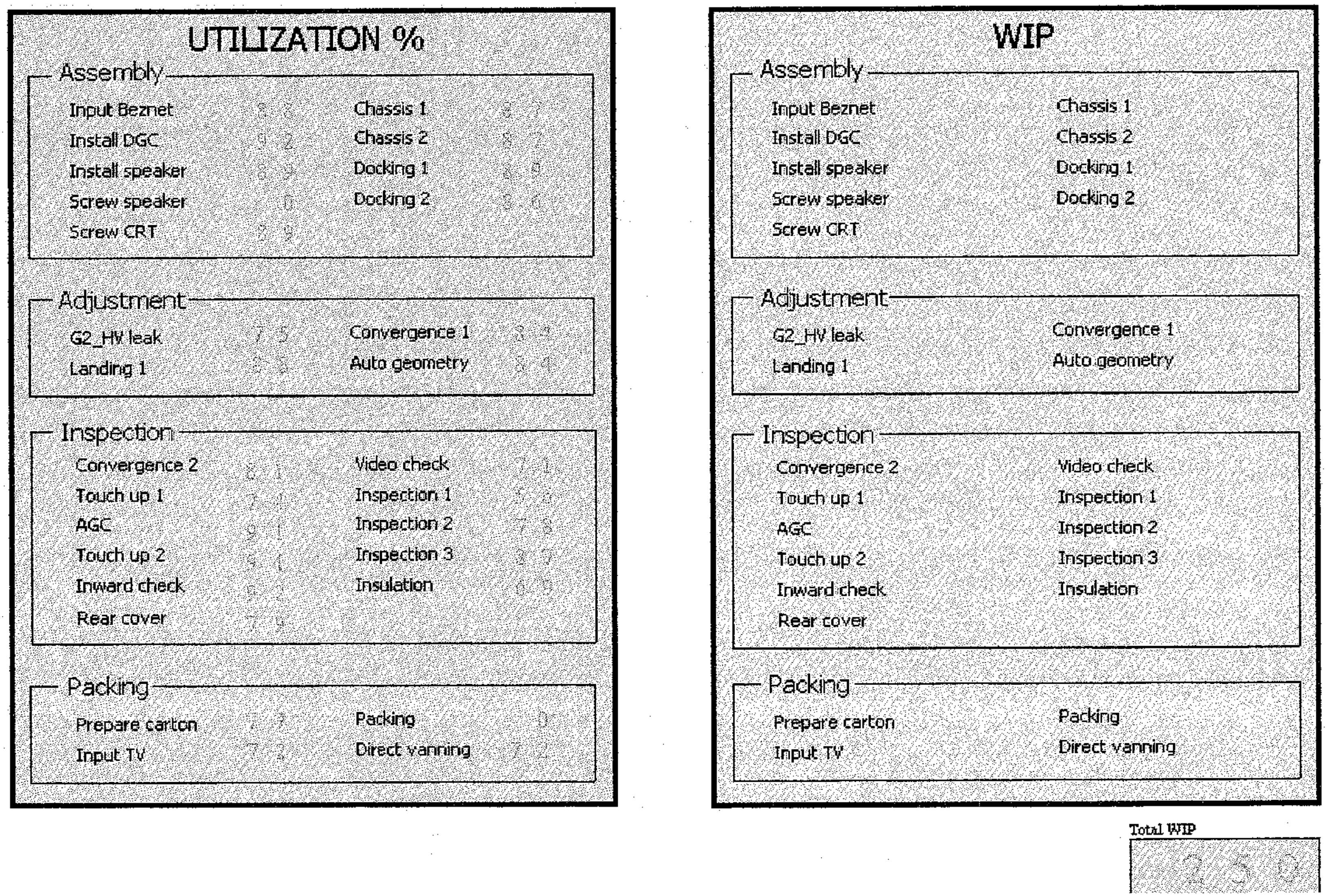
WIP and resource utilization monitoring screen



Model 2 monitoring screen



Model 3 monitoring screen

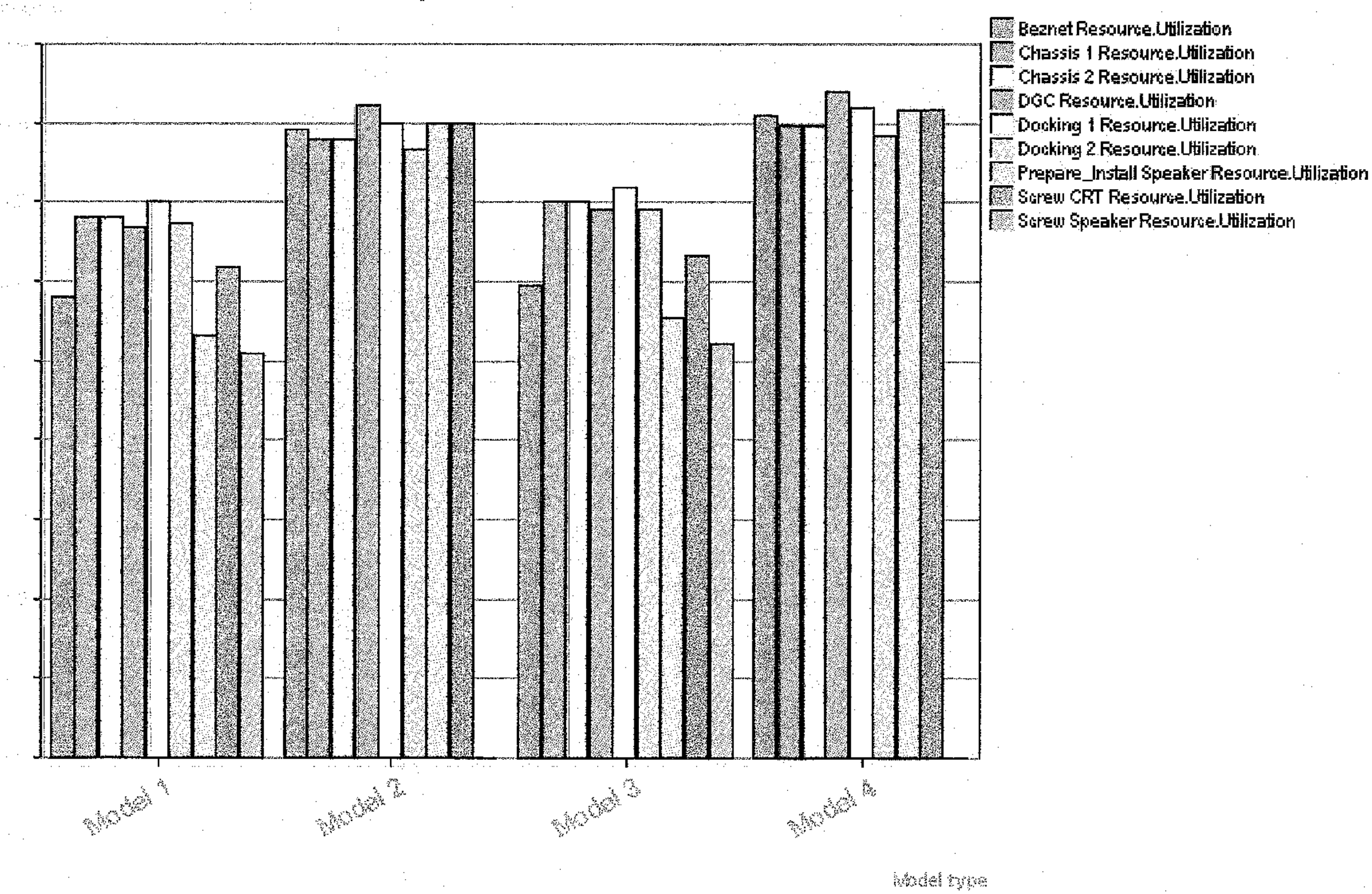


Model 4 monitoring screen

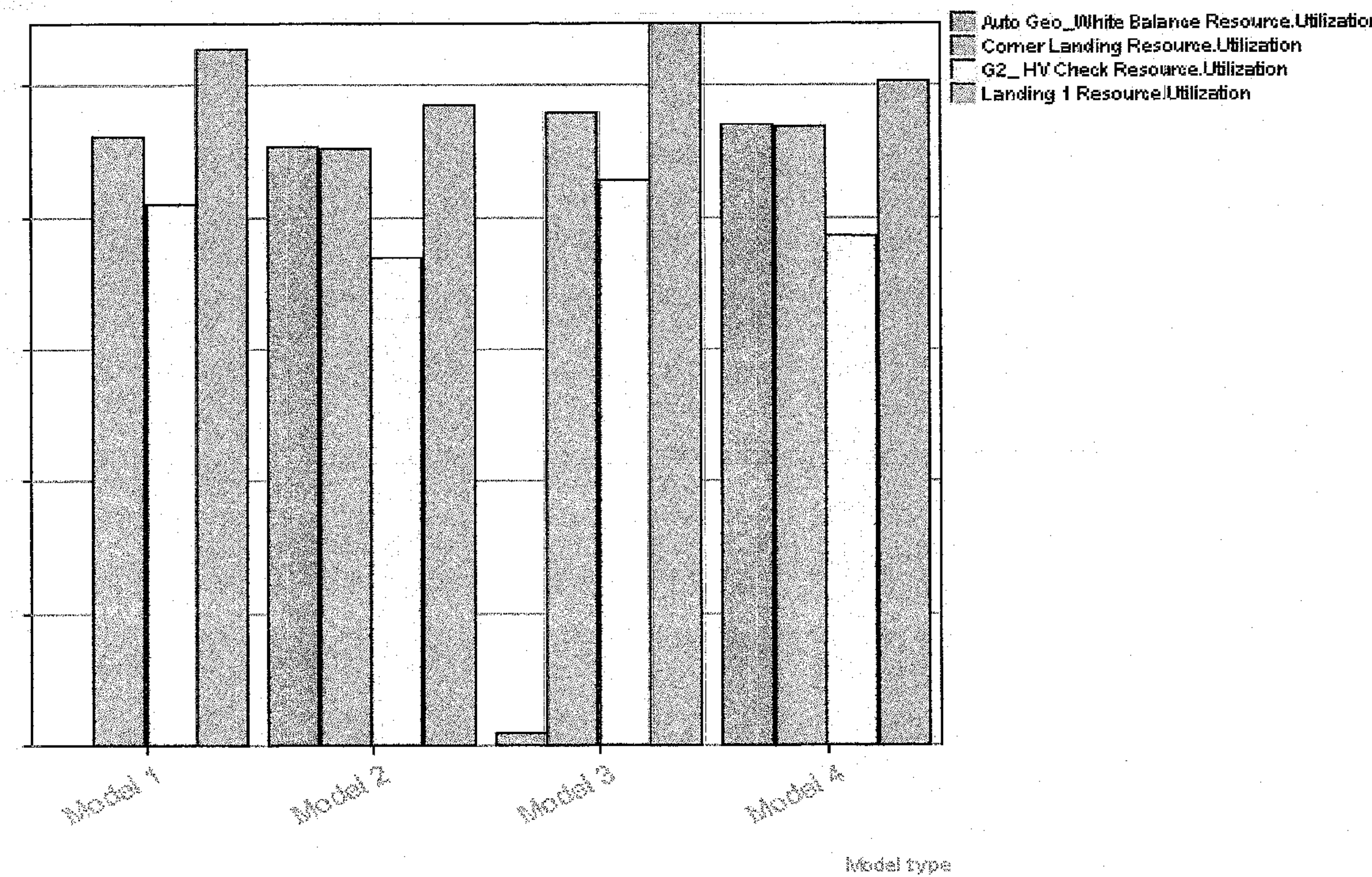
APPENDIX 10

Resource utilization charts at Process Analyzer

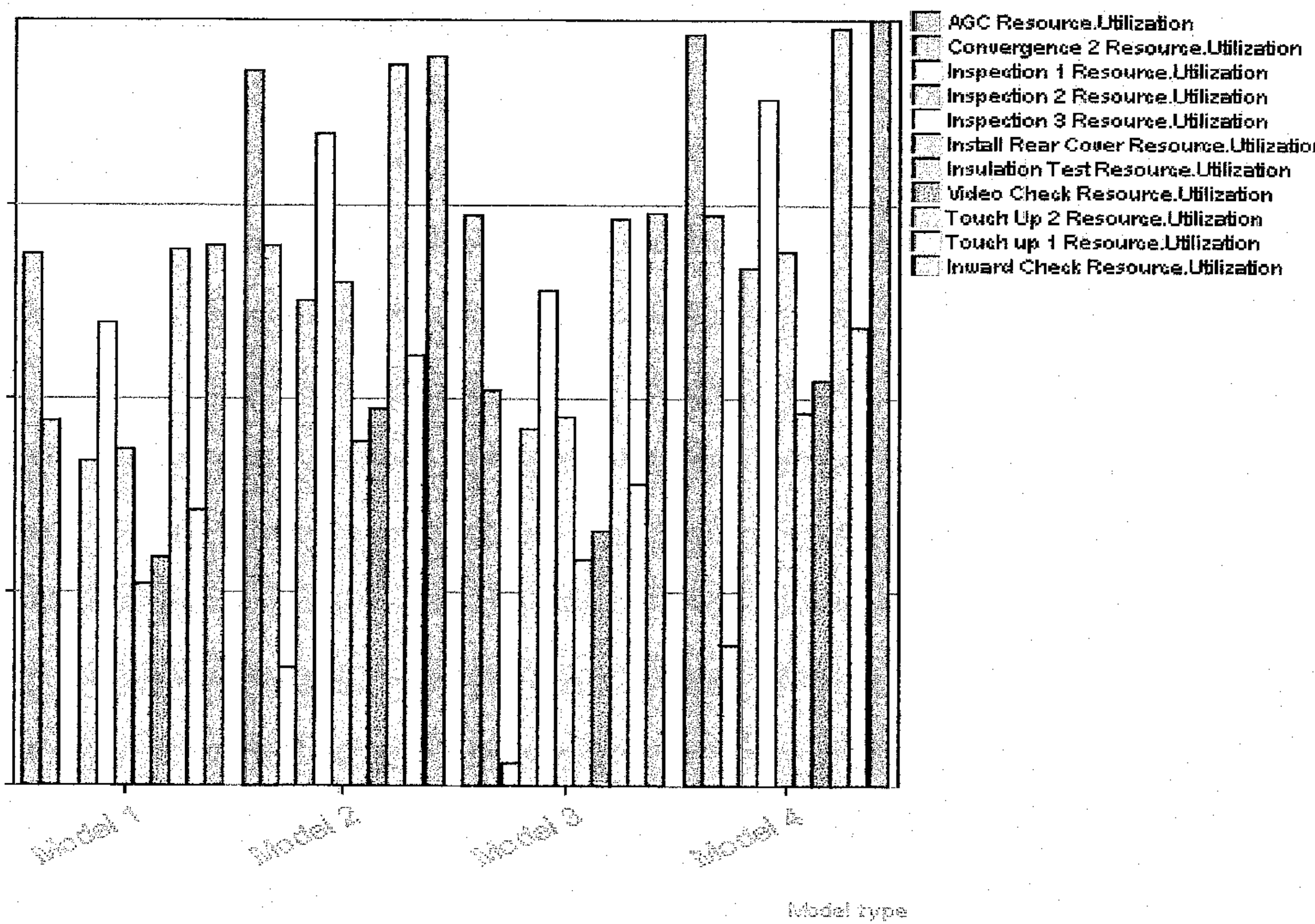
Resource Utilization for Assembly Process Area



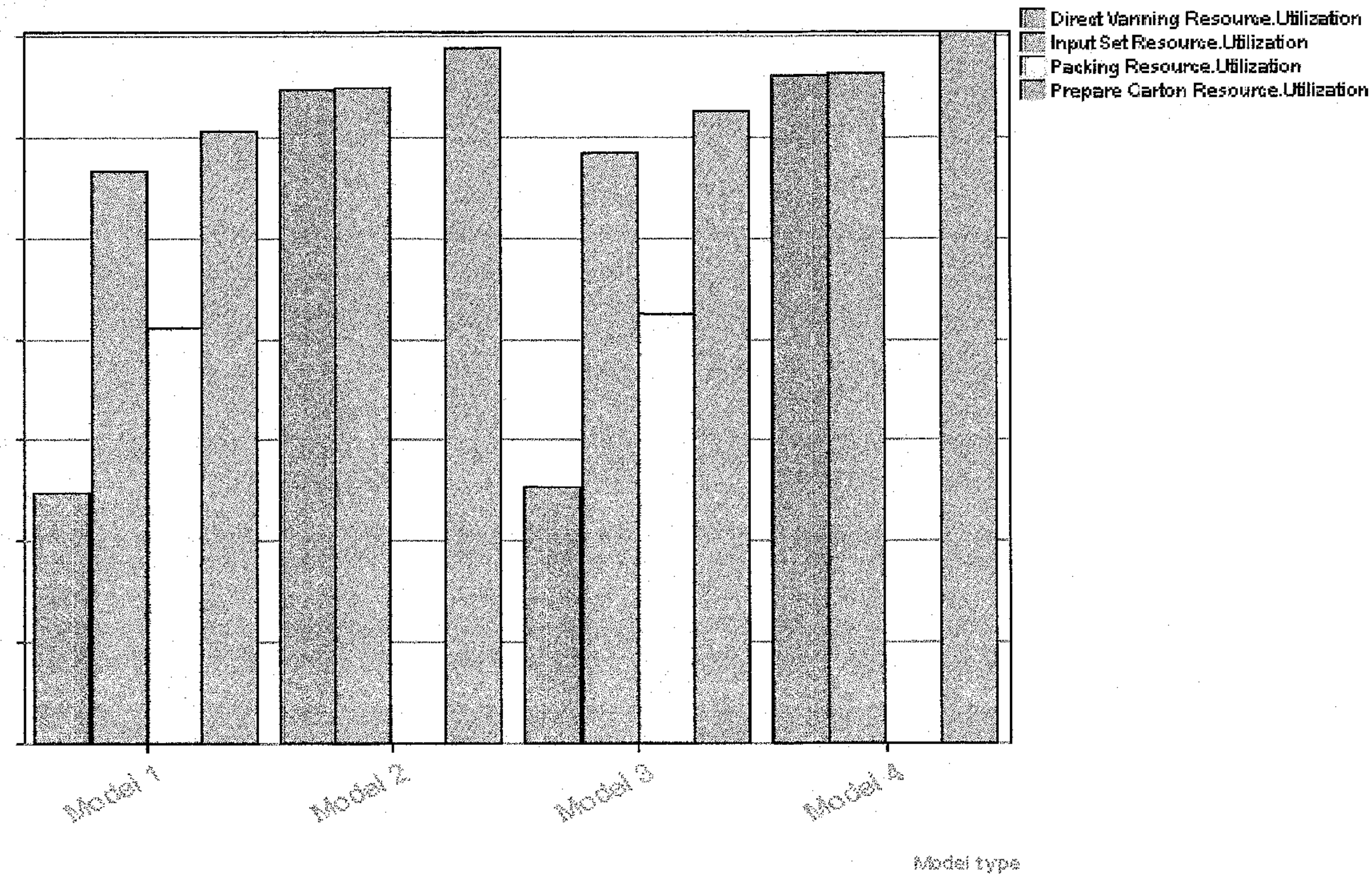
Resource Utilization for Adjustment Process Area



Resource Utilization for Inspection Process Area

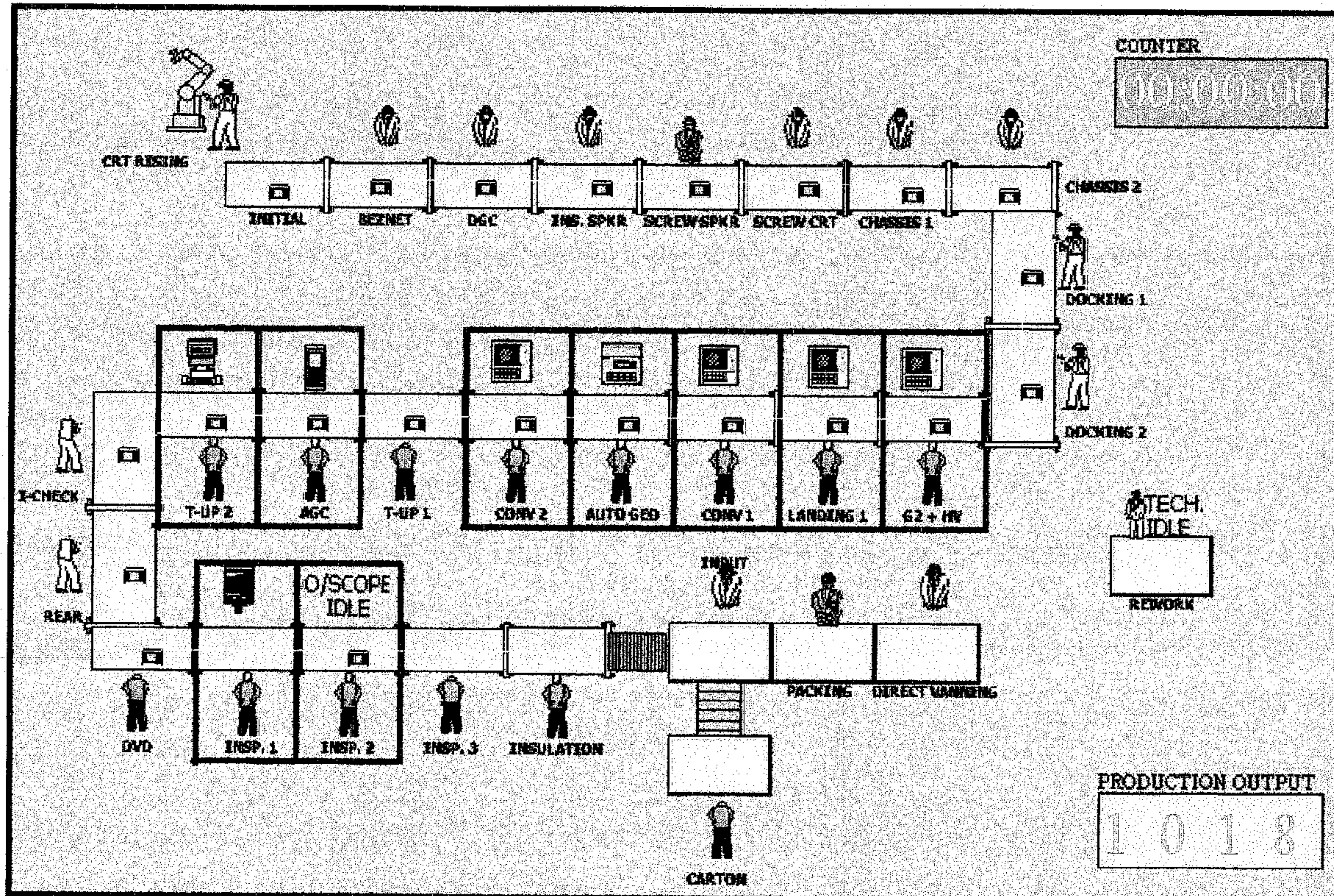


Resource Utilization for Packing Process Area



APPENDIX 11

Production output (Animation for Model 4)


COUNTER
CRT RISING
INITIAL
BEZNET
DGC
INS. SPKR
SCREW SPKR
SCREW CRT
CHASSIS 1
CHASSIS 2
DOCKING 1
DOCKING 2
I-CHECK
REAR
T-UP 2
AGC
T-UP 1
CONV 2
AUTO GED
CONV 1
LANDING 1
G2 + HV
TECH.
IDLE
REWORK
O/SCOPE
IDLE
INPUT
PACKING
DIRECT VANNING
DVD
INSP. 1
INSP. 2
INSP. 3
INSULATION
CARTON
PRODUCTION OUTPUT
1 0 1 8

APPENDIX 12

Cycle time comparison (Model 2 & Model 3)

Production Line

Replications: 1

plication 1	Start Time:	43,200.00	Stop Time:	86,400.00	Time Units:	Seconds

lly

iterval	Average	Half Width	Minimum	Maximum
AGC Process Time	39.5481	5.07711	32.2259	1,834.21
Auto Geo Process Time	17.1189	2.98744	12.4637	916.97
Beznet Process Time	30.7565	2.99086	25.4024	929.88
Carton Process Time	32.0588	2.96612	27.0113	928.55
Chassis 1 Process Time	36.7982	4.68576	30.5195	1,832.66
Chassis 2 Process Time	35.7493	4.30538	30.2530	1,832.55
Convergence 1 Process Time	42.1423	5.09853	35.3173	1,837.88
Convergence 2 Process Time	33.7142	4.39283	27.0157	1,830.09
Docking 1 Process Time	36.6633	4.29145	31.9395	1,835.43
Docking 2 Process Time	37.3568	5.03485	30.0132	1,834.39
DVD Process Time	31.7728	5.09016	25.4170	1,826.13
G2 Process Time	39.3634	5.06711	33.5663	1,835.68
Input Process Time	31.1165	4.68712	23.0366	1,828.19
Inspection 1 Process Time	24.0146	2.99490	18.0380	923.78
Inspection 2 Process Time	33.3308	4.73595	27.0031	1,829.93
Inspection 3 Process Time	37.7509	5.08687	32.0000	1,832.93
Insulation Process Time	30.0720	4.68635	24.0092	1,829.71
Inward Process Time	39.7394	5.04595	28.9899	1,836.92
Landing 1 Process Time	45.4222	5.11437	39.5013	1,842.12
Packing Process Time	21.3538	2.15498	18.3020	919.34
Prepare Speaker Process Time	27.4003	2.18334	23.0319	923.01
Rear Process Time	31.4771	2.13009	27.3205	931.46
Screw CRT Process Time	32.6647	4.23082	27.0159	1,832.51
Screw Speaker Process Time	26.1779	2.15607	23.6844	924.53
Touch up 1 Process Time	32.9679	5.07153	25.3241	1,829.80
Touch Up 2 Process Time	39.7477	5.18451	32.2024	1,835.34
Tube Process Time	37.2159	5.10067	29.3024	1,833.05
Vanning Process Time	14.3150	4.29064	10.1075	1,811.08

ı Production Line

Replications: 1

plication 1 Start Time: 43,200.00 Stop Time: 86,400.00 Time Units: Seconds

ally

ıterval	Average	Half Width	Minimum	Maximum
AGC Process Time	38.9008	4.40580	35.2900	1,835.29
Auto Geo Process Time	36.4710	4.39901	32.7600	1,832.76
Beznet Process Time	37.5621	4.40580	33.9800	1,833.98
Carton Process Time	31.6772	2.57344	29.8700	929.87
Chassis 1 Process Time	37.2800	4.40580	33.6800	1,833.68
Chassis 2 Process Time	37.2936	4.40580	33.6900	1,833.69
Convergence 1 Process Time	36.6499	4.42928	32.6700	1,832.67
Convergence 2 Process Time	33.5923	2.69748	31.3300	931.33
Docking 1 Process Time	38.2036	4.40580	34.6000	1,834.60
Docking 2 Process Time	35.9054	4.08298	33.2000	1,833.20
DVD Process Time	29.5054	2.57344	27.7000	927.70
G2 Process Time	31.1329	3.70904	29.1400	1,829.14
Input Process Time	31.7245	4.40580	28.1100	1,828.11
Inspection 1 Process Time	24.6382	4.08064	21.9000	1,821.90
Inspection 2 Process Time	32.9418	4.07880	30.1500	1,830.15
Inspection 3 Process Time	37.4972	4.40580	33.8900	1,833.89
Insulation Process Time	29.6881	4.08298	26.9800	1,826.98
ınward Process Time	39.2165	4.40527	35.6100	1,835.61
‿anding 1 Process Time	38.0149	4.40621	34.1600	1,834.16
ᵓacking Process Time	0	0.000000000	0	0
ᵓrepare Speaker Process Time	37.0486	4.08238	34.3600	1,834.36
₹ear Process Time	34.1501	4.40527	30.5400	1,830.54
ɜcrew CRT Process Time	38.0464	4.40580	34.4500	1,834.45
ɜcrew Speaker Process Time	0	0.000000000	0	0
ſouch up 1 Process Time	32.4808	4.40580	28.8700	1,828.87
ſouch Up 2 Process Time	39.1179	4.48483	35.4100	1,835.41
ſube Process Time	37.9966	4.08298	35.3100	1,835.31
/anning Process Time	29.8572	3.70161	28.0500	1,828.05